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VOL. **37.**

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

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Proceedings of the Four Hundred and Forty-First Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 26, 1906—Mr. W. H. Patchell, Vice-President, in the chair.

The minutes of the Ordinary General Meeting held on April 5, 1906, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members:—

Arthur Pirrie Haslam.	James Archibald Robertson.
Gustaf Chas. Lundberg.	Joshua Shaw.

From the class of Associates to that of Associate Members:—

Benjamin Handley.	Joseph Poole.
Laurence Joseph Kettle.	Frederick Walter Shorrocks.

Alfred Sommerville.

Messrs. J. W. Cooper and H. W. J. Peterson were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Associate Members.

Harold G. Brown.
John Ferguson.
Gwilym Aneurin Roberts.
Edwin Seddon.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. H. C. Channon, W. A. Del Mar, F. H. Nicholson, H. M. Stich, W. W. Strode, N. Tesla ; and to the *Benevolent Fund* from The Electrical Engineers' Ball Committee and F. H. Nicholson, to whom the thanks of the meeting were duly accorded.

The CHAIRMAN : I have to apologise for the absence of our President to-night ; he has to attend the Annual Dinner of the Institution of Mechanical Engineers, which accounts for my being in the chair.

It is now my duty to read the Council nominations for the officers and Council for the ensuing Session :—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE, 1906–07.

As President.

Nomination Dr. R. T. GLAZEBROOK, F.R.S.

As Vice-Presidents (4).

Remaining in Office { W. M. MORDEY. W. H. PATCHELL.

New Nominations { F. GILL. C. P. SPARKS.

As Ordinary Members of Council (15).

Remaining in Office {
W. A. CHAMEN.
W. DUDDELL.
J. S. HIGHFIELD.
H. HIRST.
Colonel H. C. L. HOLDEN, R.A., F.R.S.
WALTER JUDD.
GISBERT KAPP.
C. H. MERZ.
C. H. WORDINGHAM.

New Nominations {
S. EVERSHED.
H. E. HARRISON, B.Sc.
J. E. KINGSBURY.
M. O'GORMAN.
G. W. PARTRIDGE.
A. A. C. SWINTON.

As Associate Members of Council (3).

Remaining in Office { A. Campbell, B.A.
T. Mather, F.R.S.

New Nomination J. Hunter Gray.

As Honorary Auditors.

For Re-election { F. C. Danvers.
Sidney Sharp.

As Honorary Treasurer.

For Re-election Robert Hammond.

I have to add that, in accordance with Article 45 of the Articles of Association, if no other nominations are made within seven days, the candidates nominated by the Council will be elected at the Annual General Meeting.

There is one other matter which the Council think ought to be mentioned before we proceed with the general business of the meeting, and that is the untimely death of Professor Curie in Paris. He was not one of our members, but he was well known, and has long identified himself with the art. Some of his earliest work was in connection with piezo-electricity and on the magnetic properties of bodies at different temperatures. He came before us more prominently through the work which he did jointly with Madame Curie in the discovery of radium only a few years ago, and it is very sad that such a young and active man—I believe he was only about forty-six or forty-seven years of age—should have been cut off in the way he has been. I therefore put it to the meeting that we pass a vote of condolence with Madame Curie, and ask the Secretary to transmit it in suitable terms. I will call upon Mr. Mordey to second this resolution.

Mr. W. M. Mordey: I think I need do no more than formally second the proposal. I am sure you all feel that Science, and all the industries that branch out from Science, have suffered a very great loss in the death of M. Curie.

The resolution was carried in silence.

The meeting adjourned at 9.30 p.m.

The following paper was read and discussed :—

LONG FLAME ARC LAMPS.

By LEONARD ANDREWS, Member.

(*Paper read April 26, 1906.*)

Until comparatively recently, all tests and experiments made with arc lamps appeared to show conclusively that to obtain the highest efficiency the length of the arc should not exceed three or four millimetres. Mrs. Ayrton* shows that "almost the whole of the increased power that has to be supplied to the arc when it is lengthened is swallowed up by the mist, and is practically wasted." The following table of comparative efficiencies appears to show, however, that, whilst increasing the length of the arc beyond three or four millimetres does tend to reduce the efficiency of arc lamps with coaxially arranged pure carbons, this rule does not apply to many of the long flame arc lamps having inclined downward-feeding carbons which have now begun to be very generally used.

TABLE I.

Type.	Amperes.	Volts.	Watts.	Mean Hemispherical Candle Power.	Authority.
Ordinary Open Arc	— *a*	— *a*	440	400 *b*	Dr. Wedding.
Ditto	— *a*	— *a*	476	633 *c*	Westminster Electric Testing Laboratory.
Ditto	10	45	450	830	Calculated from Fig. 1.
Enclosed Arc ...	6·6	71	459	360 *d*	U.S.A. Photometric Committee.
Ditto	— *a*	— *a*	485	338	Westminster Electric Testing Laboratory.
Carbone H.T. Arc	9·3	89·1	820	2,080	Dr. Wedding.
Chemical Carbon Arc	— *a*	— *a*	382	1,325 *c*	Westminster Electric Testing Laboratory.
Ditto	10	46	460	2,750	Excello Pamphlet.

a Not specified. *b* Mean spherical candle power. *c* Tested with opalescent globe. *d* Tested with opalescent inner and clear outer globes.

* "The Electric Arc," page 371.

Taking the mean of the results given by different authorities, and reducing them all to a common basis by making the necessary corrections for globes and different standards of illumination, it appears that the relative efficiencies expressed in mean hemispherical British candle power of the different types of lamps are approximately as follows :—

TABLE II.

	Candle Power per Ampere.	Candle Power per Watt.
Ordinary Open Arc	82	1·54
Enclosed Arc	55	0·77
Carbone H.T. Arc	200	2·24
Chemical Carbon Arc ...	259	5·80

Whilst it is the usual and, for some purposes, more useful practice to specify the efficiency of an arc lamp in candle power per watt, it is thought that the candle power per ampere may also be a useful figure. It will be remembered that in the discussion that took place a few years ago on the question of changing the pressure of supply from 100 to 200 volts, a favourite argument used by those opposed to the change was that the majority of tradesmen using arc lamps required two lamps only, and that, should the pressure be doubled, these consumers would be forced either to alter their wiring and install four lamps where they only required two, or to absorb over 50 per cent. of the total energy in useless resistance. The introduction of the high-voltage enclosed arc lamp, however, overcame this difficulty, and in spite of its low efficiency *per watt* its use has now become very general. In considering improvements in arc lamps it is necessary, therefore, to bear in mind that, for many purposes, low-voltage lamps cannot be used to the greatest advantage.

Returning to the question of long arcs *versus* short arcs, it is an interesting fact that all the very marked improvements that have been made in arc lighting during recent years have been effected by the use of arcs of from 10 to 15 millimetres in length, and investigation shows that the great improvement in efficiency is directly or indirectly due to this increased length.

The improvements effected may be briefly summarised as follows :—

(*a*) The formation of the positive crater in such a position that none of the light emitted by it is obstructed by the negative carbon.

(*b*) The impregnation of the carbons with metallic salts, thereby rendering the flame highly luminous.

As (*a*) is not dependent upon the use of special carbons, we will consider this improvement first.

Engineers who attended the demonstration of electrical apparatus at Hastings about three years ago will remember that considerable attention was attracted by an arc lamp, of exceptional brilliancy and whiteness, which was then exhibited. An ammeter connected in series with this lamp showed that it was taking the same current as an ordinary 10-ampere arc lamp burning by its side, but the new lamp appeared to be giving between two and three times the light. It was noted, however, that a voltmeter across the terminals of the new lamp recorded a pressure of about 85 volts. As the arc was giving a remarkably white and steady light, and was not burning in an enclosed globe, this high voltage excited considerable interest. As Mr. Carbone, the inventor of the lamp, had, however, not then completed all his patents, he would only allow the results he was able to obtain to be seen from a distance. Since that time, however, the new lamp has been commercially developed in Berlin, where it appears to be finding great favour with all users, and the author has succeeded in obtaining from Mr. Carbone, and from other sources, sufficient information to enable him to explain some of the principles of the invention.

It is well known that the maximum illumination obtainable from a pure carbon arc lamp in any direction is proportional to the area of the positive crater visible in such direction, plus the light emitted by the red-hot portions of the carbons, the white spot on the negative, and the flame or arc mist; and since the area of the crater is approximately proportional to the current and is not appreciably increased by an increase of voltage, it would appear, at first sight, that to expend energy on an increase of voltage must tend to decrease the efficiency. It must be remembered, however, that for all practical purposes it is not so much the actual area of the crater that determines the useful efficiency of an arc as the area visible at any angle below the arc.

Mr. Trotter has shown that if none of the light from the positive crater is intercepted, then the candle power from this source at any angle may be represented by the radius vectors of a circle drawn to such a scale that the diameter of the circle is proportional to the candle power measured directly facing the crater.

To be able to calculate and plot the candle power from the area, the intrinsic brilliancy of the positive crater must, however, first be determined. This has been found by three different authorities * to be 146 c.p., 158 c.p., and 170 c.p. respectively per square millimetre, and as the mean of these results is 158 c.p. per square millimetre, it appears reasonable to take this figure for calculating the candle power of the positive crater from its area. There is, however, also to be taken into consideration the fact that the intrinsic brilliancy of the soft core portion of the crater is considerably less than that of the hard carbon portion, and probably does not exceed 100 c.p. per square millimetre.

Mrs. Ayrton found the total area of a 10-ampere, 45-volt crater to be approximately 18 square millimetres, of which 7 square millimetres were soft core and 11 square millimetres were hard carbon.

* Dr. J. A. Fleming, "The Photometry of Electric Lamps," *Journal of Institution of Electrical Engineers*, vol. xxxii., p. 137.

The total maximum candle power emitted by a 10-ampere positive crater, calculated on the above basis, would appear to be, therefore :—

Hard carbon, 11 sq. mm. × 158 = 1,738 c.p.
Soft carbon, 7 sq. mm. × 100 = 700 c.p.

Total ... 2,438 c.p.

Fig. 1 is a reproduction of Mr. Trotter's well-known curve constructed to such a scale that the maximum radius vector is proportional to the maximum candle power emitted by the positive crater of a

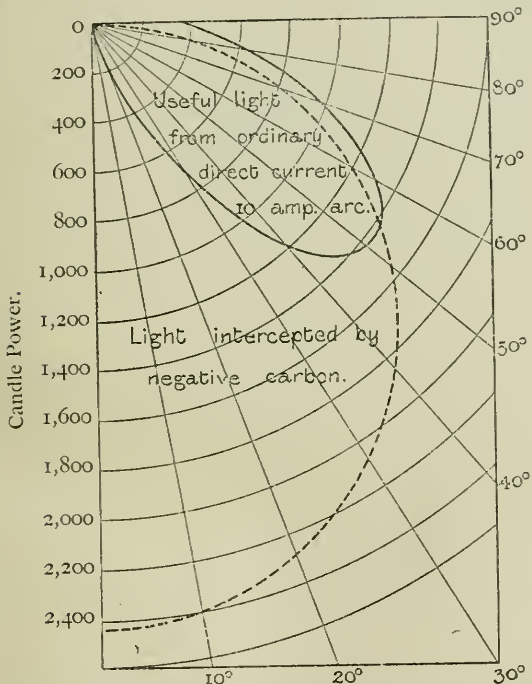


Fig. 1.—Mr. A. P. Trotter's curve, showing total light from positive crater.

10-ampere arc, namely, the 2,438 c.p. derived as explained above, and inasmuch as the apparent area of the crater viewed from any other angle is proportional to the cosine of the angle, each radius vector of the dotted circle is proportional to the candle power from the crater measured at any angle.

To ascertain the total available or useful light from an arc lamp with carbons arranged coaxially, a length proportional to the candle power intercepted by the negative carbon must be deducted from each radius vector of the dotted circle for all angles of less than 50 or 60 deg., and a length proportional to the light from the

negative crater or white spot, red hot carbons and flame must be added to each radius vector at all angles from which these sources of light are visible. This gives the well-known polar curve of a direct-current arc shown full in Fig. 1.

Objection has been raised to the use of polar curves, such as Fig. 1, for showing the efficiency of an arc, on the ground that the mean spherical candle power cannot be calculated directly from these curves. It is, however, even more impossible to determine the useful efficiency of an arc from knowledge of its mean spherical c.p. only. For instance, the mean spherical c.p. of a direct current arc would be approximately the same, whether the positive crater were at the top or at the bottom, whereas it is well known that in the majority of cases the *useful* efficiency

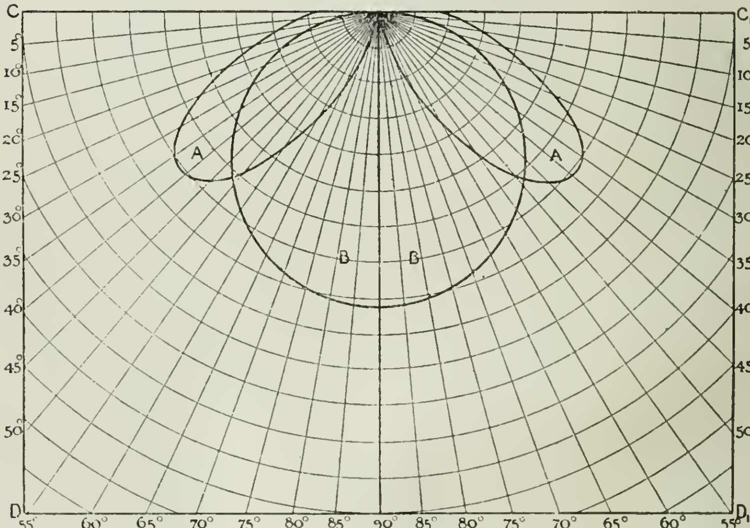


Fig. 2.

is enormously reduced by what is known as connecting up a lamp the wrong way.

The mean hemispherical candle power is a more useful figure, but this gives insufficient information for many purposes. For instance, the respective polar curves A,A and B,B, Fig. 2, show the candle power at any angle below the horizontal from two different sources of illumination. It will be found on plotting the mean hemispherical candle power from each of these curves by Rousseau's well-known method that the results are precisely the same. If, therefore, the energy consumed by each illuminant is equal, it might be claimed that the efficiency must be the same in each case. If, however, the illumination be measured directly below the arc on a given floor space of a diameter D,D1, it will be found that the average candle power per

square foot is $2\frac{1}{2}$ times greater when illuminated by B,B than it is when illuminated by A,A. On the other hand, wall spaces C,D and C1, D1, will be 29 per cent. better illuminated by A,A than by B,B. It is obvious, therefore, that a polar curve giving the candle power at any angle is the more useful guide in selecting arc lamps for any purpose than is the bare information that a certain type of lamp has an efficiency of a certain mean spherical candle power per watt.

Returning to Fig. 1, it is seen that not only is a very large proportion of the total light emitted by the positive crater intercepted by the negative carbon, but that the waste from this cause occurs in the direction in which it can least be spared. It is evident, therefore, that a very large economy can be effected by causing the positive crater to form in such a position that, whatever angle it be viewed from, none of it shall be cut off by the negative carbon.

Many attempts have been made during recent years to solve this (at first sight) simple problem. Some of these attempts have been directed towards increasing the length of the arc of an ordinary arc lamp, with the idea of thereby allowing more light to escape. In some notes on Angold arc lamps published by the General Electric Company it is stated "an increase of voltage lengthens the arc and decreases the shadow of the negative carbon, thus giving more light at a greater efficiency, but the practical limit is reached at 45 volts, when the unsteadiness from flaring counterbalances the improvement in light." Mrs. Ayrton shows,* however, that no useful object is attained by increasing the length of an ordinary arc beyond three or four millimetres, as the light absorbed by the lengthened arc mist exceeds the additional light which escapes unintercepted by the negative carbon.

Various other attempts have been made to get an unobstructed positive crater by the use of inclined carbons,† but all these experiments appear to have been carried out with voltages of from 40 to 45 volts across the arc, and at these pressures the crater forms on the side of the positive carbon, between it and the negative, instead of at the tips, and consequently, at pressures of less than 60 or 70 volts, more light is intercepted by the negative carbon with inclined carbons than with carbons arranged in the ordinary way. Mr. Carbone was the first to suggest as a solution of the difficulty the use of inclined carbons combined with a voltage of from 80 to 90 volts across the arc.

Whilst the mere appreciation of the advantage of high voltage with inclined carbons constitutes a marked advance in arc lighting, further invention was necessary to render the system practicable. Carbone also discovered a method of controlling the long arc without flickering, and succeeded in obtaining a form or shape of flame which reduces to a minimum the absorption of the light from the crater by the arc mist.

Fig. 3 shows the ends of carbons and the economiser of a "Carbone" arc lamp. The arrangement of these appears to be, at first

* The "Electric Arc," page 263.

† In the discussion on Mr. Trotter's paper Mr. Mordey suggested the use of carbons placed at an angle of 90° to each other, the arc being repelled to the tips of the carbons by a magnet.

sight, precisely similar to that of all other flame arc lamps. The essential difference, however, lies in the magnetic control of the arc. Any attempt to repel the arc to the tips of the carbons by means of a moderately strong concentrated magnetic field produces an effect somewhat similar to that of a blowpipe, tending to blow the arc into a bluntly pointed flame, extremely difficult to keep steady, and of a shape that increases the length of the arc mist to be traversed by the light emitted by the positive carbon.

The Carbone method of controlling the position of the arc is shown in Fig. 4. This consists of a closed iron magnetic circuit, the only field affecting the arc being that due to magnetic leakage from this closed circuit. The chief leakage will obviously be from the ends of the cores carrying the exciting solenoids. The magnetic circuit from the ends of these cores is completed through the iron ring. This ring, which also serves to hold the economiser in position, is fixed concentrically with the arc slightly above the plane normally occupied by the tips of the burning carbons. Holes are drilled in the ring midway between the points to which it is fixed to the core, thereby increasing the magnetic reluctance, and causing further leakage, at points approximately at right angles to the cores. The result is a weak hemispherically shaped leakage field of just sufficient strength to maintain the craters at the tips of the carbons, the shape of the flame covering the mouth of the economiser somewhat resembling that of a soap bubble covering the bowl of a tobacco pipe under very slight pressure.

Fig. 5 is reproduced from a photograph of a 10-ampere 85-volt "Carbone" arc, the incandescent tips of the carbons being just visible below the edge of the economiser. The dense portion of the flame is the violet mist, which is very similar in appearance and colour to the mist seen between the carbons of every arc lamp. This mist is surrounded by a sheath or envelope of burning gases.

Unlike the ordinary arc lamp, the length of the arc mist to be traversed by the crater light is not appreciably increased by lengthening the arc. It would appear, therefore, that by ascertaining the area of the crater visible in a given direction for voltages ranging from 45 to 100 volts, it should be possible to ascertain to what extent the high efficiency of the "Carbone" arc is directly due to the fact that the higher voltages cause the crater to form more at the tips of the carbons.

Attempts were at first made to measure these areas by projecting an image of the crater upon a screen and measuring the area of the image. As, however, the carbons could not be distinguished when taking measurements directly facing the crater, there was no reliable means of determining accurately the ratio of the area of the image to the actual area of the crater, and since a slight change in the position of the crater relatively to the lens made a large difference in this ratio, it was found practically impossible to obtain trustworthy measurements in this way. The distance from the crater to the lens would, of course, vary considerably with different voltages, assuming that the position of the lens relatively to the arc lamp is fixed.

The most satisfactory results were obtained by taking photographs

10 a

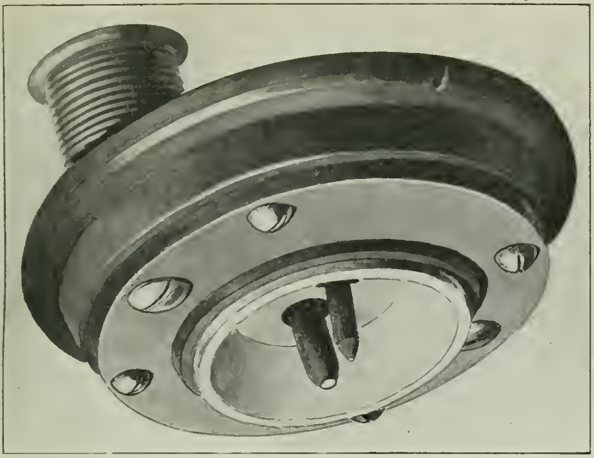


FIG. 3.

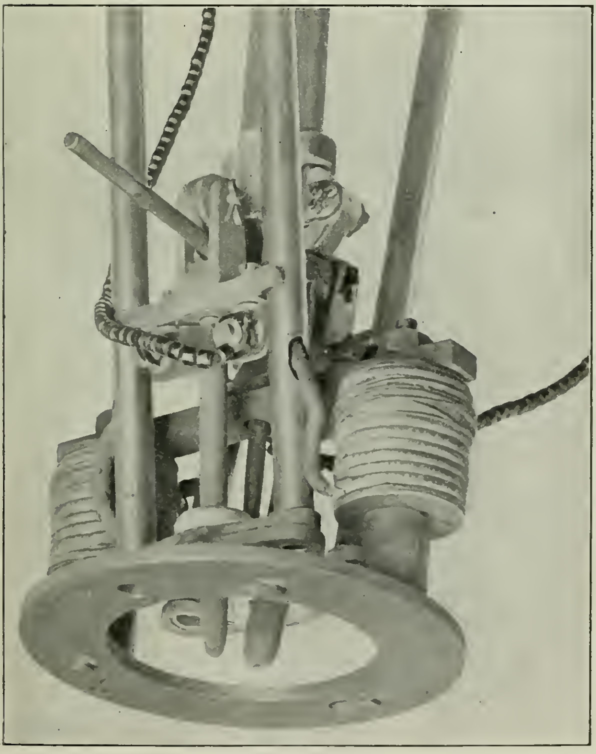


FIG. 4.—Magnetic Ring control of Carbone Arc.

FIG. 5.—Carbone Flame.

FIG. 6.—Pure Carbon Arc. L 1·5 mm.

Volts, 56. Amperes, 10·2. Area of craters visible, 3 sq. mm.
Watts per sq. mm. of crater, 190.

FIG. 7.—Pure Carbon Arc.
L 3·5 mm. L_1 7 mm.

Volts, 61. Amperes, 10. Area of craters visible, 6 sq. mm. Watts per sq. mm., 98.

FIG. 8.—Pure Carbon Arc.
L 9 mm.

Volts, 72. Amperes, 10. Area of craters visible, 9·75 sq. mm. Watts per sq. mm. of crater, 74.

FIG. 9.—Pure Carbon Arc. L 10 mm.

Volts, 78. Amperes, 9·7. Area of craters visible, 10 sq. mm. Watts per sq. mm. of crater, 76.

FIG. 10.—Pure Carbon Arc. L 12·5.

Volts, 90. Amperes, 9·6. Area of craters visible, 10·6 sq. mm. Watts per sq. mm. of crater, 82.

FIG. 11.—Pure Carbon Arc. L 13·5 mm.

Volts, 94. Amperes, 9·5. Area of craters visible, 10·6 sq. mm. Watts per sq. mm. of crater, 84.

FIG. 12.—Pure Carbon Arc. L ·5 mm.

Volts, 53. Amperes, 10·5. Area of craters visible, 3·75 sq. mm. Watts per sq. mm. of crater, 148.

FIG. 13.—Pure Carbon Arc. L 3·5 mm. L_1 7 mm.

Volts, 63. Amperes, 9·8. Area of craters visible, 5·5 sq. mm. Watts per sq. mm., 89.

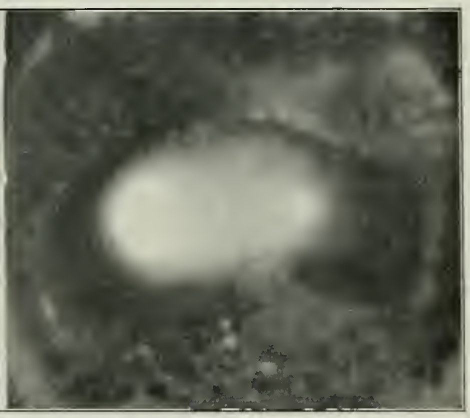


FIG. 14.—Pure Carbon Arc. L 9·5 mm.

Volts, 74. Amperes, 9·8. Area of craters visible, 15·5 sq. mm. Watts per sq. mm., 46·8.

FIG. 15.—Pure Carbon Arc. L 13 mm.

Volts, 92. Amperes, 9·2. Area of craters visible, 18·6 sq. mm. Watts per sq. mm. of crater, 45·4.

Fig. 19.—Chemical Carbon Arc. L 11 mm.

Volts, 38. Amperes, 10 *a*. Area of craters visible, 13 sq. mm.

of the crater by means of a camera having a lens fixed a definite distance from a sensitised plate, this distance being such that when the crater was in focus the diameter of the image was just double that of the actual crater. Before taking a photograph, the position of the camera relatively to the arc was adjusted to bring the image into focus, and as a further precaution, the distance between carbons and the distance of the arc from the lens was checked after each exposure. A constant enlargement of two to one was by this means ensured. Each plate was given two exposures, one being instantaneous, to obtain an image of the crater; the clutch holding the carbons was then locked in position and a second exposure of some seconds' duration was given to obtain an image of the carbons and surroundings.

The photographs reproduced were selected from over one hundred that were taken, all giving fairly concordant results.

Figs. 6 to 11 show the area of the crater visible when observed from an angle of 45 deg. below the horizontal, with voltages varying from 56 to 96, and Figs. 12 to 15 give corresponding observations taken directly below the arc. With voltages of less than 60, it will be seen that the crater forms between the carbons, and whilst the actual area is approximately the same as that of a similar current 90-volt arc, the area visible is only a fraction of the total area.

In Figs. 6 and 12, the arc is formed between the hard surfaces of the carbons only. In Figs. 7 and 13 there are obviously two arcs in parallel, one about 3·5 mm. in length across the hard portions of the carbons, and the second about 7 mm. in length between the soft core of the positive carbon and the negative carbon. This is an interesting illustration of the fact that a given voltage will maintain a considerably longer arc between a soft core positive carbon and the negative, than between a hard carbon and the negative.

The effect of gradually increasing the pressure up to 94 volts is clearly shown by the respective Figs. 6 to 15. It will be seen that to form the craters at the tips of the carbons, a pressure of from 80 to 90 volts is required. A comparison of Figs. 10 and 11 shows that no useful improvement in the position of the craters is obtained by increasing the pressure of a 9 or 10 ampere arc above 90 volts.

In Fig. 16, the areas of the craters visible directly below the arc with different voltages are plotted with rectangular co-ordinates, and a curve is added showing the efficiency in candle power per watt, assuming that the candle power is directly proportional to the area of the crater. It will be noted that this curve has a very different characteristic to the corresponding curve given by Mrs. Ayrton * for coaxially arranged carbons, which latter is reproduced in Fig. 17. This reaches a maximum at about 42 volts, and then steadily falls, whereas the "Carbone" efficiency curve continues to show a marked improvement up to 80 volts.

It has so far been assumed that the candle power emitted by the positive crater is proportional to the area of such crater, and that no appreciable proportion of the light emitted is intercepted by the arc

* "The Electric Arc," p. 382.

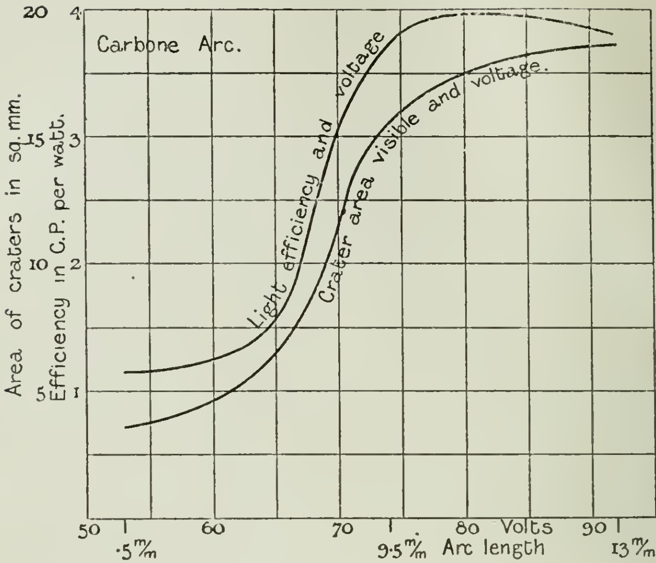

Carbone Arc.
Light efficiency and voltage
Crater area visible and voltage.
Area of craters in sq. mm.
Efficiency in C.P. per watt.
20
15
10
5
4
3
2
1
50
60
70
80
Volts
90
·5 m/m
9·5 m/m
Arc length
13 m/m

FIG. 16

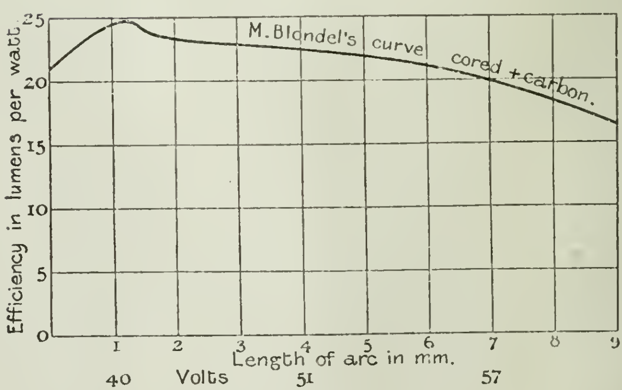

M. Blondel's curve cored + carbon.
Efficiency in lumens per watt.
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
Length of arc in m.m.
40
Volts
51
57

FIG. 17.

mist. To ascertain how far this assumption is justified, we may compare with the polar curve constructed by Dr. Wedding showing the candle power measured at a number of different angles, the polar curve constructed by multiplying the area of the craters in square millimetres by the intrinsic brilliancy in candle power and by the cosine of the angle.

The positive crater area of a 9·3-ampere 89-volt "Carbone" arc was found to be 17·1 square millimetres, of which 3 square millimetres was of soft-cored crater. The candle power emitted by the positive

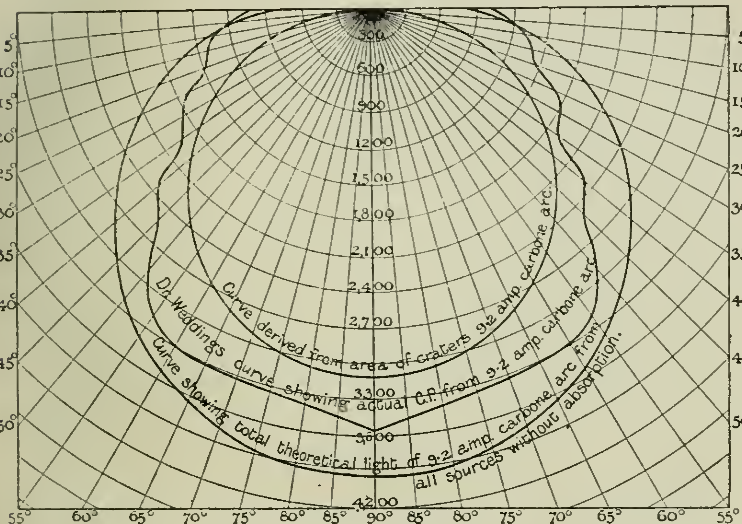


FIG. 18.

crater, plus that emitted by the negative or white spot, should therefore be :—

Hard carbon positive crater	14·1 sq. mm.	× 158 =	2,227·8
Soft-cored " "	3·0 "	× 100 =	300·0
Negative crater ...	1·5 "	× 158 =	237·0
			2,764·8

As, however, Dr. Wedding's results are given in Hefner units, it will be necessary to divide the total maximum candle power as calculated above by 0·88, the result being a maximum candle power in Hefner units of 3,142.

The polar curve A, B, C, Fig. 18, can now be constructed, the maximum radius vector being made proportional to the candle power derived as stated above. It will be seen that this curve is considerably smaller than Dr. Wedding's curve plotted from the mean of actual candle power measurements taken at a number of different angles and

in different vertical planes. We have, however, to add to the candle power derived from the area of the craters the candle power of the flame and of the red-hot portions of the carbons. The candle power from these sources in the "Carbone" arc is very considerable. Dr. Wedding found the mean candle power measured in the same horizontal plane as that occupied by the craters to be approximately 900, and as practically none of this could have come from the craters, the bulk of it must have emanated from the flame and red-hot portions of the carbons.

It may be assumed that the candle power from these sources is practically constant in all directions. We may therefore add to the radii of the polar curve representing the light from the craters a length proportional to the light from the flame and red-hot portions of the carbons. A third curve, A1, B1, C1, may now be constructed, representing the total light emitted from all sources. It would appear then that the light intercepted by the arc mist is represented by the difference between the radius vectors of curves A1, B1, C1, and Dr. Wedding's curve of actual results, always assuming, however, that the figure of 158 c.p. per square millimetre which has been taken represents the true intrinsic brilliancy of the craters. This figure is, however, probably sufficiently accurate to show that with a "Carbone" shaped flame only a small proportion of the total light is intercepted, and consequently that the high efficiency of this lamp is in a great measure chiefly due to none of the crater light being intercepted by the negative carbon.

Turning now to the second improvement effected in arc lighting, namely, that due to the impregnation of the carbons by metallic salts, even greater radical departures from hitherto accepted principles are found.

Whilst by far the chief source of light in a pure carbon arc is the positive crater, we see from Fig. 19, which is reproduced from a 10-ampere chemical carbon arc, that the area of the crater is only about 65 per cent. of the area of a 10-ampere pure carbon arc, the intrinsic brilliancy being also probably less even than that of the soft core of a pure carbon crater. It would appear, therefore, that of the total candle power of 2,750 hemispherical candle power emitted by a 10-ampere chemical carbon arc, less than 700 candle power is emitted by the positive crater. Whilst, therefore, the high efficiency of this type of arc is in a measure due to the formation of the craters in such a position that none of the light from the positive crater is intercepted by the negative carbon, it is evident that it is only partially due to this cause.

The crater area of a chemical carbon arc is in a great measure dependent upon the portion of the carbon that is being consumed at the time. For instance, in Fig. 19 it will be seen that the arc is burning almost entirely from the chemically impregnated core; whereas at the moment when Fig. 20 was taken the chemical core had become hollowed out and the crater appears to be formed on the edge of the hard carbon shell. In this position the crater area is extremely small. When the shell on the side of the positive carbon nearest to

the negative carbon has burnt away, the crater gradually travels round to the opposite side of the carbon. This causes considerable difference in the pressure across the arc, the total variation sometimes amounting to as much as 15 per cent.; that is to say, the voltage will increase from 40 volts, when the crater is on the near side of the positive carbon, to 46 volts when it is on the far side. It is interesting to note that, owing apparently to the lower resistance of a chemical carbon arc, the craters can be retained at the tips of the carbons with a very much lower voltage than is required for a pure carbon arc.

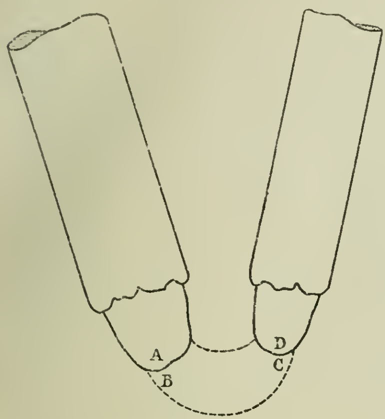


FIG. 21.

Another noticeable difference between chemical carbon arcs and pure carbon arcs is to be found in the drop of potential across the positive crater.

The following table shows the drop of voltage in different 10-ampere arcs measured between the respective points indicated by letters in Fig. 21.

TABLE III.

Volts between.	Ordinary 3 mm. Arc Lamp.	"Carbone" High-voltage Arc Lamp.	Chemical Carbon Arc Lamp.
A and B ...	34 volts	36 volts	17 volts
A and C ...	—	78 ,,	36 ,,
A and D ...	49 ,,	88 ,,	46 ,,
B and D ...	—	44 ,,	28 ,,
C and D ...	9 ,,	10 ,,	10 ,,

The bulk of the light from a chemical carbon arc emanates from the flame, and is apparently due to minute burning particles in the flame which are raised to a very high state of incandescence. It has been found that the relative intrinsic brilliancy of the flame of a chemical carbon lamp is about one-third that of the positive and negative craters.* It must be remembered, however, that the area of the flame visible at any angle is many times that of the crater, and the

* *Science Abstracts*, No. 662, 1905.

total light emitted by the flame is consequently many times that emitted by the craters.

Whilst the commercial use of chemically impregnated carbons has only come to the fore within the past two or three years, the idea is by no means new. Mr. Trotter, in his paper before this Institution in 1892, made the following reference to the suggestion :—

"Several attempts have been made to improve the arc by adding volatile substances, or by introducing gas through a hollow carbon. The only good effect that can be expected is the production of a long arc, which will reduce the shadow of the lower carbon; and it is likely that the temperature of the crater will be reduced by the presence of any substance less volatile than the best carbon."

It would appear from the above that the chief gain in efficiency due to the high luminosity of the flame was not then appreciated.

The efficiency of a chemical carbon lamp is so very much higher than it has yet been possible to attain with any type of pure carbon arc that it might appear at first sight that the use of pure carbons would very soon cease. Unfortunately, however, the advantage from the point of view of efficiency is discounted by certain defects which render this type of lamp unsatisfactory for many purposes.

The flickering noticeable in all chemical carbon lamps cannot at present be entirely overcome, though it has been greatly reduced in recent lamps. Considerable improvement has been effected during the last year or two in the composition of the carbons used for chemical carbon flame arc lamps. The large amount of calcium salts first proposed by Bremer and the non-conductive scoria caused a great irregularity in burning. The carbons are now usually of the composite type, consisting of three zones. The outer zone or envelope is composed of pure carbon, giving mechanical strength. The next contains carbon mixed with various salts, such as those of calcium and magnesium, and the inner soft centring core is made of the same materials less strongly compressed.

The poisonous fumes given off by the burning chemicals make the lamp unsuitable for use in a room not very efficiently ventilated, besides which, these fumes are very apt to injure the mechanism of the lamp.

The ash or residue from a chemical carbon arc is very much greater than from a pure high-voltage flame arc lamp. The author has obtained photographs of the ash from a 10-ampere chemical carbon arc and from a 10-ampere "Carbone" pure carbon arc after two hours' burning by placing plates of clear glass in the respective globes, these being carefully removed without disturbing the ash and used as negatives. The ash from the chemical carbon lamp was many times greater than that from the pure carbon arc.

The carbons are at present considerably more costly than pure carbons, and as the globes cannot be entirely enclosed, the life of the carbons is very short. The light is useless in positions where discrimination of colours is required.

Colour.—The colour of an artificial light is for many purposes of even greater importance than its efficiency.

Considerable difference of opinion exists as to what is the best colour, and this difference will probably remain so long as it is attempted to define any one particular colour as the best for all purposes. For the illumination of the outsides of public buildings, theatres, etc. (especially where these are built of stone), there is nothing more effective and more pleasing than the yellow colour given by the chemical carbon arc lamp. It is also the best light for penetrating a thick yellow fog. For many other purposes, however, a pure white light is generally to be preferred. What is the exact definition of the term "white light" is somewhat difficult to express. It is certainly not the violet-tinted light of the ordinary arc lamp, nor is it the distinctly green light of the incandescent gas lamp. Possibly the best definition is: "A light which makes all colours appear to be exactly the same, whether illuminated by daylight or the artificial light in question." The yellow light given by the majority of chemical carbon lamps is sometimes claimed to be similar to that of sunlight. One of the best tests of this is to examine colours, or, say, a crowd of faces illuminated by one of these lamps. It will be at once apparent that the resemblance in the effect of the two lights is extremely remote.

The nearest approach to a pure white light that has yet been attained by artificial means appears to be that of the high-pressure pure carbon arc with downward-feeding inclined carbons. That it is so, however, is somewhat surprising, as it would be expected that the very long flame of the high-voltage arc would give a very violet light. The extreme whiteness of this light is referred to by Dr. Wedding in his report on the "Carbone" arc. In discussing the cause of this, he says: "The spectroscope analysis shows a very wide spreading out in the violet parts of the spectrum alongside of a strong line in the yellow-green. Numerous lines stand out in the violet, through which no doubt the tone of the colour is called forth."

Sir W. Abney has shown that the light emitted by the positive crater of a pure carbon arc lamp is very like sunlight, but has a slight excess of orange and green rays, and a slight deficiency of blue. Notwithstanding this generally accepted fact, it is well known that the light from an ordinary arc lamp tends to make objects appear to be blue or purple, particularly when the arc is long. Mrs. Ayrton* attributes this blueness to the fact that a portion of the light from the crater in passing through the flame of the arc is reflected and refracted by minute particles of incandescent carbon, and as these carbon particles absorb the red and green rays, and allow the violet rays to pass, the light emitted by the flame or carbon mist is of a deep violet colour. It would appear, therefore, that if just the correct quantity of this violet light could be mixed with the direct light from the crater, which, as has been shown, is deficient in violet rays, the result would be an exact reproduction of sunlight. In the ordinary direct-current arc, a large percentage of the crater light is intercepted by the negative carbon, whereas, owing to the very much larger area of the flame, comparatively little of the light from it is so intercepted. The resultant mixture,

* "The Electric Arc," page 357.

therefore, contains far more violet rays than are required to produce a pure white light.

The colour effect of intercepting a portion of the light emitted by the positive crater may be shown by a simple experiment suggested by Mrs. Ayrton. If a plate of metal is interposed between the arc and a screen, as shown in Fig. 22, the shadow of the metal will be edged with a broad band of violet light, this being the portion of the screen illuminated by the refracted light from the carbon particles constituting the arc mist.

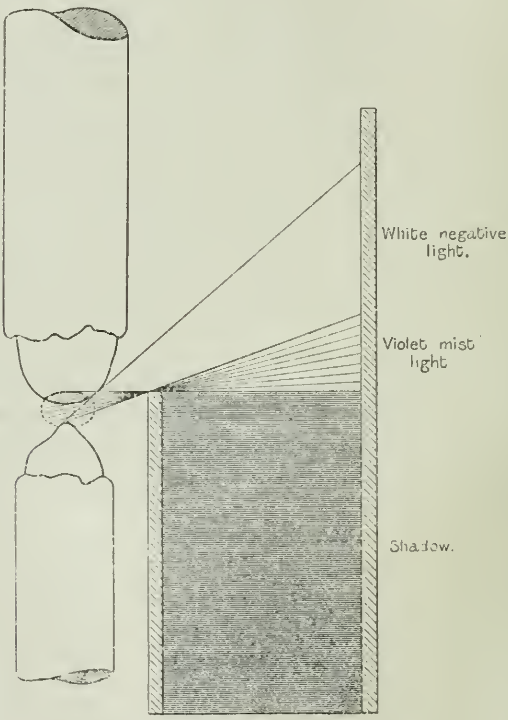


FIG. 22.

Now it appears reasonable to argue that the interception of some of the direct rays from the positive crater by the negative carbon of an ordinary arc lamp must have the same effect upon the total colour of the light as the metal screen referred to above. The fact, therefore, that none of the crater light of the "Carbone" arc is intercepted may, at any rate partially, account for the pure whiteness of this light. It is also noticeable that the light from the flame itself is by no means so violet as that of an ordinary arc lamp. This appears to be due to the large area of the sheath of burning gases. Is it not possible that this sheath is the cause of the numerous dark lines which Dr. Wedding

observed in the violet portion of the spectrum, and to which he attributes the tone of the colour? Certainly the portion of the arc mist which is not sheathed by burning gases (namely, the upper portion of the hemispherically shaped flame) does emit a light which is intensely violet. This very violet light is thrown up into the mechanism between the carbons and the insulating carbon guides.

General Effect and Distribution of Light.—It is interesting to note that arc lamp designers have during recent years paid very much more attention to these points. There is no doubt that for effective lighting the globe should have the appearance of being *full* of light. The popularity that has recently been attained by several types of enclosed arc lamps is undoubtedly in a great measure due to the use of small globes, and whilst the efficiency expressed in the "mean hemispherical candle power per watt" is considerably lower than that of the large globe open-type arc, the efficiency expressed in the "satisfaction to the general public per watt" is considerably greater. The long flame arc is particularly well adapted for use with small globes, and all flame lamps, whether of the chemical carbon type or of the high-voltage pure carbon type, always appear to give a good globeful of light. This effect is also in a great measure due to the absence of shadows resulting from the use of inclined carbons.

It must be remembered that the general public do not judge of the efficiency of any system of lighting by taking photometric tests. It would probably be much better for the electrical industry if they did. Their usual method of judging a light is, first to look at the source of light, to satisfy themselves that there is a large area of light-giving surface, and secondly to examine the ground directly below the lamp they are judging. The engineer, however, recognises that it is of even greater importance to know what is the minimum illumination midway between lights than it is to know the maximum illumination directly below the arc.

It is well known that at least 40 per cent. of the light emitted by an arc lamp is intercepted by the opalescent globe. This waste, with ordinary arc lamps, appears to be necessary, in the first place to prevent the dazzling effect which would result from an unscreened arc fixed at a position that comes within the natural angle of sight, and in the second place to give a diffused light, or the effect of a light emitted from a large surface. Dealing first with the screening effect necessary to prevent dazzling, this need not be considered if the source of light can be placed at such a height above the ground that it does not come within the natural angle of sight. It appears, in fact, that we might take a lesson from nature. At mid-day, in midsummer, when the sun is directly above our heads, and consequently not within the natural angle of sight, the light emitted by it is comparatively unscreened, and is blinding to look at, even for a moment. When the sun is setting, however, and is consequently directly within the angle of sight, such a large percentage of its light is intercepted or screened by the atmosphere that we are able to distinguish objects clearly which are in a direct line between ourselves and the sun.

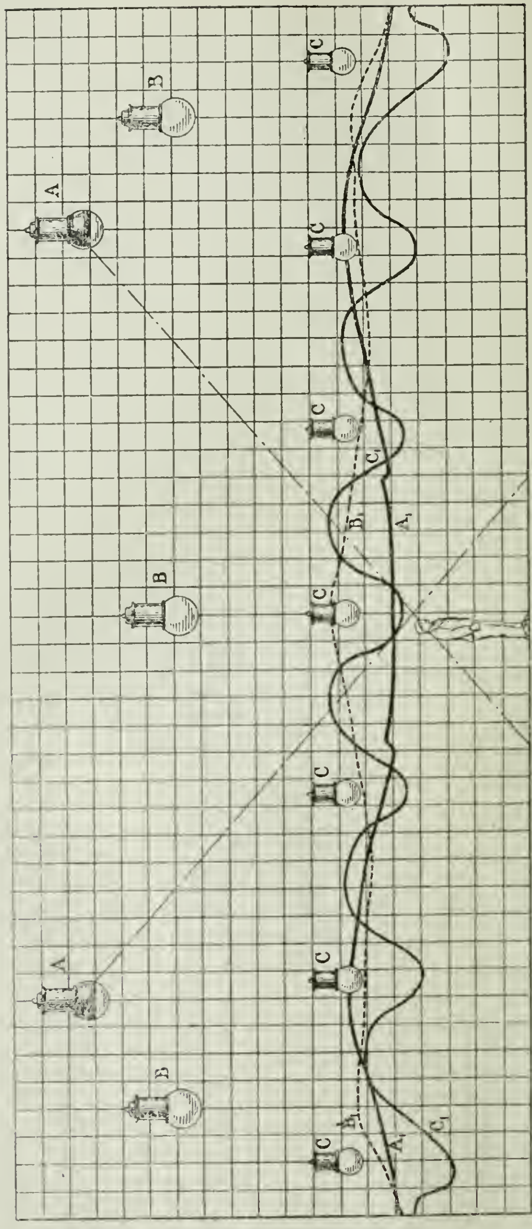


FIG. 23.

Owing to the fact that with an ordinary arc the bulk of the light is emitted at angles of less than 60° below the horizontal, it is necessary to place such lamps comparatively near the ground to get efficient results from them. This objection does not, however, apply to long flame arc lamps in which the maximum light is directly below the arc. It appears, therefore, that for many purposes, such, for instance, as for lighting large buildings, where the source of light can be placed 30 ft. or 40 ft. above the ground, it is unnecessary to use densely obscured globes. It is suggested that for this purpose long flame arc lamps should be used, fitted with globes of which the lower half is unobscured.

Curves A1, B1, and C1, Fig. 23, show respectively the illumination on the floor space of a room illuminated by 800-watt, high-voltage, pure carbon long flame arc lamps with globes half unobscured at A, A, 25 ft. above the ground, and with similar lamps fitted with globes, absorbing 40 per cent. of the light at B, B, B, 20 ft. above the ground, and with 460-watt ordinary enclosed arc lamps at C, C, C, etc., 10 ft. above the ground. It will be seen that the mean illumination is approximately the same in each case, but that a considerable saving of energy is effected by using unobscured flame lamps 25 ft. above the floor level. It is also noticeable that the distribution of light is much more even with the few lamps placed high up than with the larger number of lamps nearer the floor. Fig. 24 shows the arrangement of lamps required to produce a given mean illumination over a given floor space, the energy expended with the three systems being respectively as follows :—

	Watts.
Four 800-watt unobscured high-voltage flame lamps ...	3,200
Eight 800-watt obscured " " " ...	6,400
Thirty-five 460-watt enclosed arcs	16,100

It is obvious that by doubling the height of all the lamps a floor space of four times the area would be illuminated to one-fourth the brilliancy, the relative illumination over the larger floor space being similar to that represented by the curves A1, B1, and C1, Fig. 23.

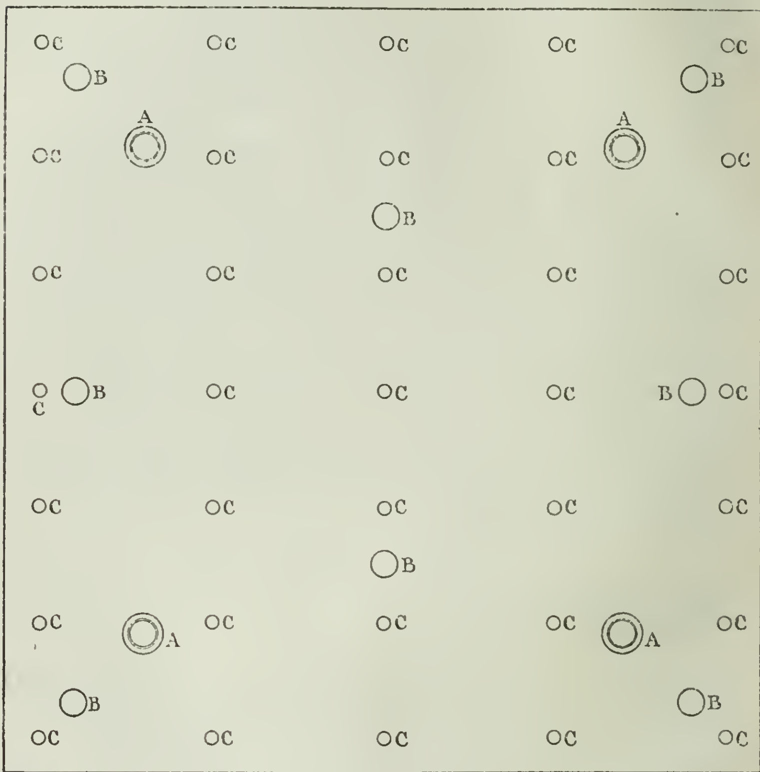
Alternating-Current Arcs.

Alternating-current lamps are very unpopular in this country on account of their very low useful efficiency. This is in a great measure due to the fact that about 50 per cent. of the light is thrown up into the air, where for many purposes it is entirely wasted. This defect, however, disappears in long flame downward-feeding carbon arcs, as the whole of the light emitted by both craters is thrown down. Dr. Wedding has found that the efficiency of an alternating-current lamp of this type is practically similar to that of a direct-current arc of the same type.

The author has obtained a photograph showing the area of craters of a 10-ampere pure carbon high-voltage arc, the current being 10 amperes, voltage 67, and the area of the craters 15·3 square milli-

metres. The watts per square millimetre of crater area are therefore 44. They are consequently no greater for this alternating-current arc than for the 10-ampere direct-current arc illustrated in Fig. 15.

Another objection to alternating-current arcs is that, when connected across an alternating-current circuit of less than 50 cycles per



Carbone 10 amp 90 volt lamp with partially obscured globe.

" " " " " " " totally opaque globe.

O 6 amp. 70 volt enclosed arcs with opalescent inner and clear outer globes.

Fig. 24.

second, the flickering is very objectionable. It appears that this difficulty may also be considerably lessened by using downward-feeding carbon arcs in which both craters are visible directly below the arc. As in the ordinary coaxially arranged carbon arc only one crater is visible from any position during one entire half of each cycle, there must of necessity be a dark period between each flash of light. This can be shown by focussing an image of the crater formed on the upper

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FIG. 20.—Chemical Carbon Arc. L 11 mm.

Volts, 40. Amperes, 10.

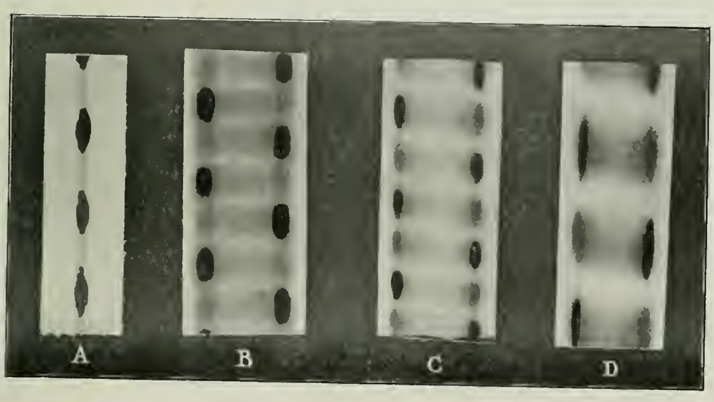


FIG. 25.

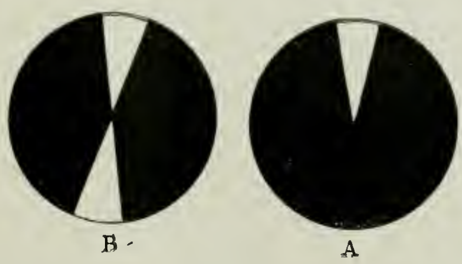


FIG. 26.

carbon of an ordinary arc on to a piece of bromide paper fixed to a drum which may be rapidly rotated. The record obtained will be similar to A (Fig. 25). B (Fig. 25) is a reproduction of a record obtained as described above from a downward-feeding pure carbon arc, and C is taken from a downward-feeding chemical carbon arc. As in both B and C the craters on both carbons are visible from one point, when the one is giving its maximum illumination the other will be at a minimum.

If a black disc with a white sector is rotated at 50 revolutions per second below an ordinary alternating-current arc burning on a 50-∿ circuit, the disc will appear as at A (Fig. 26), clearly showing that the white sector is illuminated once only during each revolution of the disc. If the disc is rotated at a speed of 25 revolutions per second, it will appear as at B (Fig. 26), showing that it is illuminated twice during each revolution. Again, if the disc is rotated at 50 revolutions per second, and the arc is connected across a 100-∿ circuit, it will have the same effect as reducing the speed of the disc to one half. If now the disc is illuminated by a downward-feeding carbon lamp connected across a circuit of a periodicity corresponding to the speed of the disc, it will appear as at B (Fig. 25). This experiment appears, therefore, to show that a downward-feeding carbon lamp on a 50-∿ circuit gives the same effect as an ordinary lamp on a 100-∿ circuit.

Record D (Fig. 25), taken with a downward-feeding lamp on a 25-∿ circuit, also shows, when compared with record A, that the maximum periodicity of illumination is the same with the downward-feeding arc on the 25-∿ circuit as the ordinary arc on a 50-∿ circuit.

The thanks of the author are due to Mr. F. Bartholomew for much valuable assistance in carrying out the various experiments referred to in this paper.

Discussion of April 26, 1906.

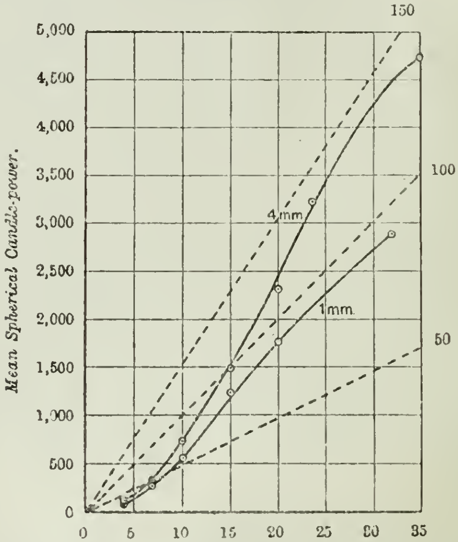
Mr. Trotter.

Mr. A. P. Trotter: The first table is a little difficult to grasp; the results, I think, are hardly comparable from the way in which they are stated. In the second table, an attempt is made at giving the candle-power per ampere. If the four results are all taken on the same basis, the comparison may be a good one; but I do not think it is possible, and Mrs. Ayrton denies it is at all possible, to take candles per ampere.

It is true that the candle-power per sq. mm. (to which I will refer again later) is approximately constant, and that the area of the crater is approximately proportional to the current; but there are three other important factors. The first of these is the diameter of the carbons. The diameter of the positive carbon is easily settled; if it is too small the arc will hiss, if it is too large the crater will wander. The negative carbon must carry the current satisfactorily and should be as small as will stand handling. The other two are the volts and the length of arc, and these depend on each other, as Mrs. Ayrton has so fully discussed. I am not aware that anybody has completely investigated the most efficient arrangement of all these factors, but even if such were done,

Mr. Trotter.

I do not think it likely that the candle-power would be found to vary directly as the current. Mrs. Ayrton (page 366, Fig. 116) gives 55 mean spherical candle-power per ampere for 10 amperes with 13/11 carbons, with 1 mm. arc, and 75 m.s.c.p. for 4 mm. arc length. With the same length and the same carbons she obtained about 90 m.s.c.p. per ampere with 25 to 30 amperes. With the same carbons and an arc length of 4 mm. the m.s.c.p. per ampere was 75 for 10 amperes, and was 140 for 30 amperes. Facing the curves from which I have deduced these figures, Mrs. Ayrton gives one of M. Blondel's diagrams. He plots "total light in lumens" against amperes, and gives curves for 6/6, 10/10



Current in Amperes.—Curves (from Mrs. Ayrton's book) connecting Mean Spherical Candle-power with Current for Constant Lengths of Arc of 1 mm. and 4 mm. Carbons: Positive 13 mm. cored; negative, 11 mm. solid. Dotted lines added, for 50, 100, and 150 Mean Spherical Candle-power per Ampere.

and 18/18 carbons, not very practical combinations. Thanks to Mrs. Ayrton's index we need only turn back to page 330 to find that a "lumen" is 4π decimal candles, or Hefner units. A "lumen" is therefore 0·07 spherical candle-power. Blondel's curves relate to 45 volts. At 10 amperes he obtains 45 m.s.c.p. per ampere with 18/18 carbons, closely agreeing with Mrs. Ayrton, but with the same current and 10/10 carbons he gets 65, and with 6/6 carbons over 90. The curves all rise, showing higher candle-power per ampere with larger currents.

The watt measurement is even more difficult when you are dealing with watts per candle, because you have such a great variety of ways of using up volts in an arc lamp. It is an important matter from the economical point of view. If you have so many kilowatts to spend, the best way of applying those kilowatts is to produce the greatest

candle-power possible. The intrinsic brilliancy of the arc has been taken at the lower part of page 6. There, again, there is a discrepancy between different values, because one is not sure that everyone is measuring the same thing. One of the earliest and one of the lowest figures was made by M. Voit, at Munich Exhibition, who got only 48·4 candles or thereabouts per sq. mm.—they may have been Hefner units. In the experiments which I made in 1892 at Finsbury (or rather which were made entirely by Mr. C. F. Higgins, because I only looked on and made suggestions; Mr. Higgins did the whole of the work, and he ought to have been associated with me in the title of the paper), most of the work was relative, but there was one attempt at candle-power made against a standard candle. We got there 64 candles per sq. mm.; that is a very low figure. We took the whole crater, right up to the very fringe—I am not quite sure how much was taken, but it was a very large amount of crater. In the discussion on my 1892 paper, Professor Thompson and Mr. Swinburne suggested that a square mm. of the crater of an arc would form a good unit of light. When I went into the subject rather fully and took pains to get the best bit of the arc and to get the maximum, I found it was impossible on account of various rotatory phenomena in the arc which I, and afterwards Mrs. Ayrton, noticed. I obtained 170 c.p., but this was the maximum and about the best, and it by no means represents the mean brilliancy of the total crater. There, again, if various experiments are made on the same basis, a comparison may be all right. The three curves which have been calculated in Fig. 18 certainly appear to be concordant, and the author makes a very good case for the way in which he gives and takes and explains those curves, but I think that there are several factors which are difficult to determine accurately, and I am inclined to think that that innermost curve cannot be depended on within, perhaps, 20 or 30 per cent. Mr. Trotter.

The next point I have noted is a small one, but I think it is worth mentioning. In Fig. 1 on page 7 the author has produced a curve from my 1892 paper, and a good deal of the polar curve of the arc comes outside the semicircle. This is not an accurate copy of my curve. One must not credit the negative light and the flame light of an ordinary arc with quite as much as would be indicated in the curve in the author's paper. Fig. 2 is a good example of the necessity for care in interpreting the meaning of polar curves. The usual expression, the "length of the arc," is not used in the same sense by the author as it was by Mrs. Ayrton and others who have made careful measurements of this length. When Mrs. Ayrton speaks of the length of the arc—and a large amount of her work depends on that—it is the vertical length of a straight line. Here we are dealing with a curve; the straight line would be the chord of such a curve. Probably a good deal of Mrs. Ayrton's work would be applicable to the length of that curved line. The flame of the arc, until these new chemical lamps came out, contributed very little to the light; I do not think it played such an important part in the colour of the light as the author thinks, but I will allude to the colour afterwards. It is as though for many years we had

Mr. Trotter.

been accustomed to nothing but non-luminous flames, like Bunsen flames or water-gas flames, and then somebody discovered the carburetted flame like that of ordinary gaslight. The flame of the arc lamp has been almost as useless for illumination as a Bunsen flame, but now some one has succeeded in imparting a colour to it—and a very horrible colour I think it is. It is still in its infancy, however, and I dare say somebody will be able to cure it. I am told that the colour of the mercury lamp has been cured by new chemicals lately, and there is room for improvement here, no doubt.

Coming to the question of colour, I alluded in 1892 to this subject, and I must say I have nothing to withdraw from the remarks that I made on that occasion. In that paper I quoted Sir W. Abney and other authorities. The way to judge of the colour of an arc lamp is not to look at it at night at all—you have no scale of white—but to look at it on an ordinary grey day, of which we have so many in this country—I do not say a sunny day, in the sunshine or in the light of a clear blue sky, but on a grey day; and if you look at the light shed by tolerably good arc lamps with tolerably good carbons under those conditions you will see that it is of a pale primrose or straw colour. The mere fact of night coming on cannot alter that colour. The question is (disregarding the blue flickers which we get with very inferior carbons), why does an arc lamp look blue or violet at night? It may be said philosophically that if nine hundred and ninety-nine persons out of a thousand say it appears to be blue, it *is* blue, for blueness is only an appearance. I say that if a light is straw-colour in the daytime it must be the same at night, and if it appears to be something else at night that is an illusion. I gave two or three reasons to account for this illusion. One is that our standard of white becomes altered altogether at night. We have been accustomed for many generations to see yellow lights at night. This sheet of paper is the whitest thing in the room, but it is actually at this moment bright yellow. I dare say some of you have stayed at a ball long enough to know that daylight looks a ghastly blue when we have got thoroughly accustomed to yellow at night. Another reason is that at night the blue-seeing nerves of our eyes are rested; the yellow- and orange-seeing nerves get more or less tired, and if you give them a light with a little less yellow and red than usual, having a false standard of white at the time, the light appears to be blue. The author says that these lamps which we have seen appear to be whiter than an ordinary arc lamp. Granted that is so, I think the reason is because it is yellower. I have not seen one of these lamps by day, but I fancy if you examine one of them in broad daylight with an ordinary arc lamp which appears to be blue, it would appear to be a deeper primrose colour. That is only a suggestion which can be easily proved.

Repieff, Jamin, Killingworth Hedges, and the maker of "La Lampe Soleil," have tried to get rid of the obstructing negative carbon, and for some reason or other have failed to make a success. I hope that this resuscitation of the idea will be more fortunate.

Mr. Harrison.

Mr. HAYDN T. HARRISON: I think Mr. Andrews is to be congratulated on having given us a very interesting paper, and some very

Mr. Harrison.

excellent photographs and figures which apply to them in a wonderfully accurate way, considering that some of them are measurements and some of them are calculations; but I do not altogether congratulate him on the object that apparently has resulted in the Carbone arc lamp. It is perfectly true that by taking away the shadow of the lower carbon the mean hemispherical candle-power has been increased by increasing the candle-power directly under the lamp. But it has been my object, as I have generally had to deal with lighting very big areas, to reduce the candle-power directly under the lamp and increase it more towards the horizontal in order to get even illumination, which latter should be the object aimed at in every case. The curves shown in Figs. 23 and 24 puzzled me exceptionally when I first saw them. It does seem curious that the illumination between the lamps should be higher than the illumination exactly below them; this is only feasible by crowding into a very small area a very large number of lamps. Mr. Andrews does not give us the dimensions of the area, but I conclude that as he talks about square feet, it is probably intended to be 100 ft. by 100 ft.—the marking, at any rate, leads one to believe that; in which case the enclosed arc lamps giving 400 c.p. are only 17 ft. apart and 10 ft. from the ground. That is not a condition which is likely to exist in practice. I do not know the dimensions of the room in which this meeting is being held, but, roughly speaking, I should think the room is about 100 ft. long. If you were to crowd thirty-five 400-c.p. lamps into this room, it would be an absolutely abnormal condition, and therefore this illumination curve has, to my mind, been produced under abnormal conditions. I went into the figures for those particular tests, taking for granted that the space was 300 ft. by 300 ft., which would have been a more normal condition. Under those conditions, using eight Carbone lamps, the maximum horizontal illumination at any point would be 5·6 candle-feet; the minimum horizontal illumination at any point would be 0·29 candle-feet, a difference of nineteen times. That is not anywhere near as even an illumination as 35 lamps would have given; for instance, then the maximum illumination would have been 2·2 candle-feet and the minimum illumination 1·6 candle-feet, which is only 1·65 times. That is the horizontal illumination; that is to say, the light measured from all sources on the floor space of that particular area. I rather fancy Mr. Andrews may have added together the direct illumination from the various sources, but this would, of course, be wrong, as the direct rays do not illuminate all sides of an object when viewed from one point. I hope Mr. Andrews will explain exactly how he did come to compile those curves, because I spent a good deal of time in trying to repeat them, and I have not succeeded. The question of the type of carbons used in each particular lamp for these tests is very interesting. Of course, Mr. Andrews knows as well as any of us that this will affect the candle-power of any arc lamp as much as anything; that is to say, if he is using a very high quality soft carbon for the tests on the Carbone arc lamps it would be unfair to compare those tests with the tests shown in the early part of the paper, many of which were carried out under ordinary working conditions with the carbons which

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people can afford to use in practice. It will also affect to a large extent the colour of the light with an arc that length. Mr. Andrews has invented a new factor, which I have never come across before; he mentions in one place "the satisfaction of the general public per watt." That is a very interesting factor, but he defines it later on in a rather curious way. He says that the satisfaction of the general public per watt—I do not remember the exact words—is obtained by looking at the lamp and seeing if there "is a large area of light-giving surface," and then "to examine the ground directly below the lamp." But I think the public are getting a little more educated than that now. If that was the only object to be attained, all you would have to do would be to use a very dense globe, which would absorb the light and thus produce the large area of apparent light-giving surface, and leave a hole in the bottom of the globe in order to get the best splash of light underneath the lamp. But somehow Mr. Andrews seems to have taken that seriously, because he has done that. He takes a globe which he makes very opaque for the bulk of its surface, and he leaves a hole, or rather a clear space, in the bottom, and thus obtains a brilliantly illuminated circular area. But that would look very curious if he spread the lamps over such a large area as we generally have to light by means of arc lamps. You can imagine walking down a street in which arc lamps were erected at intervals all the way down the street with these beautifully clear, brilliant holes in the bottom of them. This is just what we try to avoid, but curiously enough is just what the Carbone lamp aims at, for it gives you the maximum rays below the lamp, and the horizontal rays are comparatively few. When I first heard of the lamp three years ago it was a great novelty; we were not used to lamps with these inclined carbons, and I doubt whether we should ever have seen or heard very much of that type of lamp if it had not been for the introduction of the impregnated carbon; Mr. Andrews himself points out that these impregnated carbon lamps are efficient, not on account of the crater light at all, but simply because they produce a flame, which has a very big illuminating power, and the light which emanates from that flame is in the direction we want it to a very large extent. There is no doubt that the yellow colour of these lamps has got beyond the stage at which we care about it for general illumination purposes, and in that respect the Carbone lamp is distinctly superior. I think that if the "satisfaction of the general public per watt" were really brought down to figures, it would be found to bear some relation to the cost per candle-power, which generally represents a large factor in the satisfaction of the public. From this point of view, I wish Mr. Andrews would give us more figures as regards the Carbone lamp; for instance, the life of carbons, quality, etc., cost of trimming, and so on. I quite agree with Mr. Andrews about erecting all these types of lamps as high as possible, and I only wish we could succeed in persuading people to do it. But there are a great many difficulties in the way, and though the same point would apply just as much to the ordinary open-type arc lamp as to the Carbone arc lamp, yet we find lighting committees object to lamps being placed over 20 ft. from the ground, at which they certainly

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should be placed in the streets. For the interior of buildings it is an equally important matter. Apparently Mr. Andrews wishes us to learn lessons from Nature; would he like us, for instance, to vary the height of our lamps during every hour, so as to be able to please everybody?

Discussion at Meeting of May 10, 1906.

Mr. Duddell.

Mr. W. Duddell: I did not know that I was going to be called upon to discuss Mr. Andrews's paper, but as I have been for many years interested in the physics of the arc, I am very glad to have the opportunity of asking Mr. Andrews some questions. Mr. Andrews spoke in his paper of soft carbon cores: I should like a definition of exactly what constitutes a soft core. Is it mechanically soft, or is it electrically soft, or what is the softness? My own experiments some years ago, using alternating currents and adding impurities to the core, showed that the softness which is usually spoken of really consists in the presence of some foreign body in the core, and that what you want to make the arc burn at a low voltage (which a soft core is generally supposed to do) is to add some volatile salt, preferably of one of the alkaline metals, to the core. In some experiments I then made, using alternating currents, I found that salts of potassium or of sodium enormously increased the apparent conductivity of the arc flame, and enabled one to burn the arc with lower voltages; in fact, so far from requiring a core that was very soft, a piece of glass rod put in place of the core in the carbon (glass being a fairly hard body) enabled one to burn the arc with a very much lower voltage than if it had the ordinary core in it.

Another point in Mr. Andrews's paper is the question of the absorption of the light. I should very much like to know whether Mr. Andrews has made any quantitative measurements of what this absorption amounts to. Mr. Andrews has a curve showing the total theoretical light and one showing the actual light; the difference is supposed to be caused by absorption. I should very much like to see some good measurements made of the absorption by carbon vapour. In the ordinary carbon arc I still feel, with all due deference to Mrs. Ayrton's work, that the absorption by the actual arc column is not very large. It is possible, in the type of lamp that is now being discussed, in which the flame is giving light and therefore is acting as a radiator, that there is a very large absorption band—in fact, theoretically there should be; but in the ordinary arc lamp, where the arc column is comparatively a non-luminous body, I do not yet feel quite convinced that it accounts for the large absorption that has been attributed to it.

I am very much interested in the mechanism Mr. Andrews has shown for obtaining a magnetic field to deflect the arc in a suitable manner. The result obtained seems excellent, but I should like to ask Mr. Andrews if he can explain what exactly the hemispherical magnetic field is like. What I am not clear about is this: Consider the earth, and let it be cut by a plane containing its axis; then do the lines of force which constitute the Carbone hemispherical field radiate from

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the North and South Poles and follow the lines of longitude, or do these lines of force follow the lines of latitude so that they are contained in a series of parallel planes? If we know the exact shape of this magnetic field, it may turn out that there are several easy methods of producing it. It should be useful for a great many purposes, especially for projectors and things of that sort.

The photographs Mr. Andrews gives of the different types of arc are very interesting, especially the one in which the arc was apparently burning between two separate craters in parallel. This seems to me to have great physical interest, because in the ordinary way one looks upon an arc as being an unstable conductor, such that you cannot burn two in parallel without adding resistance to make it stable. If you have one arc burning and attempt to start a second one in parallel, it will promptly put the first out. I should like to ask Mr. Andrews what exposure he gave these photographs. Is it possible that the arc was first burning to one crater and then jumped over very quickly to the second crater while the exposure was going on, so that we have got an appearance as if there were two craters, although there were never two craters actually at the same instant? It is a little difficult to conceive of two unstable conductors (and the arc is really an unstable conductor) operating in parallel. I have made a certain number of experiments to try and burn two arcs in parallel, but I have never yet succeeded, as the first arc was out long before I succeeded in striking the second.

I should like also to refer to Fig. 25, which is a very interesting figure, showing some records of how the arc lights up between the two carbons, and showing the light given by the vapour column. Curve C in Fig. 25 shows a distinct slant in the image of the vapour column, as if one end of it lit up later than the other. May we take it that that slant represents the rate at which the gas becomes incandescent? If it does, it gives us some idea of the rate at which the ions are travelling across that arc. M. Blondel many years ago published a very large number of records obtained on rapidly moving photographic plates. By that means he determined the rate at which the arc lights up, and, I believe, found that the arc started to light up from the negative crater first; then it started on the positive and the two met in the centre.

Mr. Gaster.

Mr. LEON GASTER: I have listened with great interest to the paper read, but from the title used for the paper by Mr. Andrews, I was expecting to hear a great deal more about the latest improvements made in the use and manufacture of the long flame arc lamps. I must express my disappointment on the choice of the title, and I should venture to suggest to the author that he changes it to either "Long Flame Arcs," or, in order to be more appropriate, to "The Long Flame Carbone Arc Lamp," as most of the paper deals with the merits of the Carbone lamp, although a few more particulars fully describing the efficiency of this lamp would have been welcome.

Without wishing to dilate on the great progress made with the use of flame arc lamps, or to describe to you some of the familiar types now used, I take leave to bring before your notice a new lamp, which, although it is as yet in the experimental stage, seems to me worthy of

mention, that is the "Vogel" flame arc lamp. For this lamp it is claimed that it possesses the advantages of excessive long burning hours, and has the efficiency of the mercury vapour lamp. Mr. Gaster.

The essential feature of the lamp is that the lower carbon stands in mercury amalgam, and when the lamp is switched on, a luminous arc is at once formed, which heats the lower carbon and evaporates the mercury. The evaporation requires only a few moments, and increases the luminous arc and the intensity of the light, as the radiant light of the hot mercury vapours is added to the original light of the carbon arc.

As the mercury vapours together with the luminous arc are enclosed in a glass globe, the vapours cannot escape, and when condensed on the walls of the globe they are always returned to their general reservoir. The lamp will burn for 1,200 to 1,600 hours with a single pair of carbons and yield an intense light, from 300 to 30,000 c.p., at a consumption of 0·2 to 0·4 watts per candle. The inventor gives for a lamp consuming 12 amperes and 50 volts and using 14-mm. carbons, an hourly consumption of 0·25 mm. for the positive electrode and 0·10 mm. for the negative electrode.

I am mentioning this lamp only for the possibility it seems to me to open for further researches to be made in the direction of increasing the efficiency of flame arc lamps, and make them to be long-hour burning, which is somewhat difficult to obtain with most of the types commonly now used. (For further particulars regarding this lamp I would refer you to the *Electrotechnischer Anzeiger* of March, 1906.)

Another lamp of which much has been expected, but little made known up to the present, is the "magnetite" arc lamp, in which one of the electrodes consists of black oxide of iron mixed with salts of chromium, titanium, etc., so as to increase the life, quality, and efficiency of the arc, and as positive electrode copper is used, the arc produced is stated to give the nearest approach to daylight. Although this lamp is used in the States I have not as yet seen any in this country. The useful life is given from 150 to 200 hours' burning for one trimming. The lamp takes about 4 amperes and 80 volts, and burns with an efficiency less than 0·5 watts per candle-power. I understand that new designs are now made for this lamp, to burn on 110 and 220 volt circuits. The lamp is not used on alternating circuits, except with mercury vapour rectifier and constant-current transformer. In street work the bulk of the light is thrown down at an angle of 10 or 20 degrees below the horizontal.

Further progress in flame arc lighting is expected to be made by the proper selection of the materials used as electrodes or used for making the cores of the carbons, and of which there is a large selection available. According to Mehlke a steady arc, and with higher efficiency, can be obtained by using different materials for the impregnation of the two electrodes, and he suggests that for the positive carbon metals should be used which form a base, like, for instance, fluor-spar and magnesia, and for the negative carbon metals forming an acid, like tungstic acid and chromium fluoride. Others suggest the use of salts of silicon and cadmium; others will use carbon calcium and magnesium, etc.

Mr. Gaster. At this juncture I should like to refer to a very interesting research carried out by Dr. C. Jaschke on the influence the presence of metallic salts has upon the visible part of the spectrum of the arc. From the tests made it appears that the efficiency of the arc can be greatly increased by proper selection of the materials used in the manufacture of electrodes employed in the flame arc lamps. The value of spectroscopical analysis is not to be underestimated.

Referring to the remark made by the author that the ordinary flame arc lamp gives off poisonous vapours when burning, and cannot be used therefore in enclosed rooms, I should like to know whether the author has made any tests to actually ascertain the nature of the vapours given off, and the extent to which they are poisonous; and also, whether the test mentioned has been made with lamps using different kinds of electrodes. This is a very important point, worthy of careful study, and ought to be clearly explained, as it would be rather a pity that the flame arc could not be used in enclosed rooms on account of the alleged poisonous vapours given off, the lamps being otherwise very efficient. I can corroborate that in the use of some of the flame carbons in enclosed rooms, an action is going on which seems to affect the air in an enclosed room, but how much the same can be avoided by the use of proper ventilation or by the use of specially prepared carbons, I am not as yet in a position to define. Some of the flame lamp makers claim that no such poisonous vapours are produced by using the carbons they employ. I think that this question ought not to be left unsettled, as it might prejudice the use of flame arc lamps for indoor purposes.

Regarding the question of the colour with which some flame lamps are burning, and which the author considered objectionable, I should like to point out that it is now possible to obtain carbons impregnated with all sorts of salts, so as to give you any colour effect desired from deep yellow to almost perfect white or day light. I have no hesitation in predicting that with the increased demand for flame carbons improvements will be made, not only to produce any colour effect, but to lengthen their life and to reduce their price considerably.

The author of the paper seems to have readily accepted the figure of 40 per cent. as representing the minimum light absorption of globes, without allowing any margin for the variety of globes now in use. I should like to know whether the author has made any tests to confirm this figure, because, from recent researches made, it appears that the percentage loss in light by absorption is not so high, and that it is a direct function of the nature of the glass used and the condition in which the globes are kept.

I am glad to see that Mr. Andrews has included in the paper a new but useful factor, with which one will have to reckon in the future more than was the case, probably, in the past, and that is "the satisfaction to the general public per watt," and, if I may be permitted, I should like to say that the satisfaction spoken of is dependent on another factor, namely, "the efficiency of the illuminating engineer," which is very variable. In view of the great number of new inventions and improvements which are constantly

being made, not only in electric lighting systems, but also with other illuminants, I think that the time is ripe for starting to specialise in the art of illumination, by making it a separate branch of the engineering profession, and raise thereby the status of the illuminating engineer, to the benefit of the public and the lighting industries alike. Mr. Gaster.

Mr. Justus Eck: I should like to take exception to the definition, or rather, the statement, given in the paper of the candle-power per ampere. It seems a pity that such a lax statement should go forth from this Institution. The question of arc lamps is quite involved enough, with the maximum candle-power, the mean hemispherical and the mean spherical, without having this possibility added to it of misleading the general public, who are the buyers in the first instance, and very often the sufferers later on. I would like to see it made a rule that all lighting devices should be sold by their mean hemispherical candle-power or their mean spherical candle-power, as it may be, together with a statement of the consumption measured on the meter and the number of lamps that can be burnt on the very many varying central-station voltages throughout this country. It is true that all people who have interests in supplying and fixing devices for the consumption of current have regretted the raising of the voltage from 100 to 200, and in many cases up to as far as 250 volts; but in my experience there are ways of getting over this difficulty. In many cases where lamps are required for special display purposes, I have used, for interior lighting, lamps of half the ampere capacity (and in some cases enclosed arc lamps) in series during the day-time or at times when the light is required inside and not out, and paralleled these in series with outside lamps of double the ampere capacity after dark, thus giving a consumption during the times of daylight, when the interior light only is requisite, of one-half that metered in the evening. The interesting point of this paper is undoubtedly the solution of the question how to project the light from the crater of an arc lamp in the direction required for illumination. A few months ago I saw a projector constructed somewhat on this principle, with the carbons at right angles and also a magnetic arrangement. In that case the positive carbon is fixed in the axis of either the reflector or the lens, thus taking advantage of the principle that has been made clear in this paper. Coming to the Carbone arc lamp, I would like to know if there is any air-circulation over the carbons, and whether the temperature is raised or lowered in consequence of this circulation or absence of circulation; in fact, it will be interesting to know what is the temperature of the arc. So far as I can remember from Mrs. Ayrton's classic book, there is a description in it of an experiment made with direct-current arcs burning pure carbons, with baffle plates of clay above the upper carbon, and it was found there that although the temperature was raised, the efficiency of the arc was not increased. It would be interesting to know what exactly is done in the particular lamp which has been exhibited and so carefully studied. Further than that, is there any possibility of enclosing the lamp, so as to obtain still longer burning hours from Mr. Eck.

Mr. Eck. the carbons that are used, or does that immediately mean a sacrifice in the luminous efficiency? One speaker this evening has already touched upon the question of the quality of the carbons, and I should like to know whether the reader of the paper has made any experiments with regard to different qualities of carbons for this class of light, that is to say, with different qualities of pure carbons and of salted or impregnated carbons. Turning to Fig. 23, it is stated that that gives a curve of illumination per square foot. I do not know exactly what is meant by that, because it appears to me that the illumination per square yard would give an equally interesting curve—in fact, that it would give the same curve. I take it that it is a curve of illumination and not of illumination per area. Mr. Andrews has mentioned the alternating-current arc and the experiments that Dr. Wedding made with it. I have not had the opportunity of reading Dr. Wedding's paper, but I would very much like to know what the actual facts are with regard to an alternating-current arc of this pure carbon type. I have reason to believe that the efficiency is exceedingly poor, and not so nearly approaching that of the direct-current arc as one is led to believe by looking through the paper. The question of the products of combustion of yellow flame arc lamps has been touched upon. I have had considerable experience with lamps of that class, both for outdoor and for indoor use, and I think that it generally solves itself in this way—that such places as require an arc lamp of that large candle-power are generally sufficiently well ventilated either automatically or purposely. I have in my mind one instance last winter where there were no less than 100 of these yellow flame arc lamps in one enclosed building, and a great number of people went to the Christmas sales there. I took the trouble to go and see if I could observe any bad effects, and I also asked the shop assistants, who were there during the whole of the day —because this place was lit practically from morning till evening—whether they had felt any bad effects. Even they could trace no bad effects there. The very fact which has been mentioned this evening, namely, that if one is at all sensitive in the throat one may notice the products of combustion, seems to me more or less a safeguard, because it calls forcible attention to the matter long before there is any dangerous or poisonous effect. The word "poisonous" has been used, but I do not quite understand what the author means by it. The last page of the paper is exceedingly interesting to me, because it mentions experiments made on a 25-period circuit. There appears from the photographs to be a sort of continuity in the illumination, but I should like to know what is the effect upon the eye of the observer—whether one can actually use a 25-period flame arc for any practical purposes, and also whether it is stable enough.

Mr. Hoadley. Mr. E. E. HOADLEY: In the one or two observations I have to offer on the paper I would like the meeting to think I am looking at this matter of long flame arc lamps purely from the point of view of the central station engineer, who is responsible to the ratepaying public for the lighting of the streets of a town. My first point with regard to the Carbone arc lamp is that, as it is at present made, the wattage

consumption (about 850 watts) is far too high for general use in what I will call the smaller towns. There are very few towns where the streets are of sufficient width or of sufficient importance to warrant one putting up units of light taking as much as 850 watts. I would like the people who are responsible for the introduction of flame arc lamps into use to produce a reliable flame arc lamp consuming somewhere about 250 to 300 watts. I am sure that a flame arc lamp consuming about that wattage will have a very large use in what I may call the smaller towns of this country. With regard to the use of pure carbons, as they are called, in this Carbone arc lamp, Mr. Andrews has said that in the generality the chemical flame arc suffers from flickering. For the past four or five months I have been making experiments prior to replacing all my existing co-axial carbon arcs by means of flame arcs, and I have never found in the actual chemical flame arc lamps which I have been trying that there is the slightest trouble from flickering. The arcs that I have been trying are quite as steady as any ordinary co-axial carbon arc. I would like to impress on the arc lamp makers the importance of getting a greater length of burning than is usual with most of the ordinary flame arc lamps—getting it either by the use of a magazine feed, or, if it is possible, by enclosing the arc. I am afraid, however, that from the very nature of the flame arc enclosing it will be no good, because it seems to me that in most of these chemical flame arcs the products of combustion must be got rid of, or the enclosing globe, whether it be large or small, will be very soon rendered practically obscured glass. With regard to the colour of the light, while I recognise that the colour of the Carbone arc lamp is exceedingly good for some things, I have, during the past few weeks, been making inquiries from what is usually called the "man in the street" as to the colour of light which is preferred for street lighting. In nearly all the inquiries that I have made the answer has been that a pale golden light—not the bright orange light which is given by some chemical carbon arcs, but a pale yellow light—is very much preferred for street lighting to what is generally known as the white light of the Carbone lamp or any ordinary arc lamp. At Maidstone we have in some of the streets flame arc lamps run on the same circuit in actual series with 10-ampere Brockie-Pell lamps, and the yellow light from the flame arc lamp is very much preferred by the populace at large to the white light given by the ordinary carbon Brockie-Pells. But for the lighting particularly of large drapers' shops I think the white light given by the Carbone lamp is much more suitable than the yellow light given by the chemical flame lamp. I have spoken to one or two large drapers, and they have told me that, while the flame arc lamp is very useful for advertising purposes, it is totally unsuitable for use inside, where there has to be much colour-matching. I should like to confirm what Mr. Eck has said about the action of the chemical fumes given off by chemical carbon lamps. I have not had such an opportunity as Mr. Eck has had of making experiments in a place where 100 lamps are alight, but some short time ago I did have a chance of making

Mr. Hoadley.

Mr. Hoadley. experiments in a room where nearly 20 chemical carbon lamps were in use for a good many hours each day. I certainly never noticed anything in my throat, and I could not find anybody else who had noticed any ill effects obtained from the fumes given off by the burning carbons. I should like to ask Mr. Andrews whether it is possible to absolutely enclose a flame arc lamp, and whether a flame arc lamp, either using pure carbon or some chemically impregnated carbon, can be possibly made in which the arc is enclosed, so as to get a good deal longer burning hours without going to the complexity of a magazine feed.

Mr. Patchell. Mr. W. H. PATCHELL: I think we have another very good instance of the benefits to the industry of competition in the state of long flame arc lamps at the present time. Years ago we were content to rest on our laurels for the time being, having captured the street lighting from the gas companies. Then they got their high-pressure gas systems, and it looked as if the electric lighting companies would have to take a back seat. In some places, due to influences of different kinds, the arc lamps were turned out and gas lamps put in. I think we may be allowed to congratulate ourselves on the success we have had at Charing Cross Station, not very far from where we are meeting, where you will remember the roof has fallen in. That has compelled the railway company to reconsider their system of lighting, owing to the different level at which the new roof will be put up. The gas company got the ear of the railway directors, and there was a tight fight for it, but the result has been eminently satisfactory to the Electric Lighting Company. We had more than one competition. The gas company persuaded the management not to take the electric company's word for it, but to have an actual exhibition and competition, and so on several evenings we had experiments. We had at last eight Sale-Onslow high-pressure lamps to compete with, and we put up five oriflamme lamps, and price for price we beat the gas company hollow. On the night that the matter was settled, we had the directors of the railway company on the platform, when the gas and electric lamps were tried alternately. If you had heard the "Oh"! of the onlookers when the electric lamps were put out, I think you would not have needed to wait until the board meeting to hear from the railway company what the result of the competition had been. On the basis of price for price we estimate that we can give the railway company 45,000 c.p. as against the 20,000 c.p. of the gas lamps. We have been using the long flame arc lamp for a long time, and have had a great many tests with it. I have a few figures with me, which may be interesting to those people who have not yet touched it. The figures are all reduced to the cost per 1,000 c.p. per hour, the current being taken at a uniform price of 2d. per unit.

I was much struck when I went over to the States last autumn to find that they had practically no flame arc lamps. I attribute that to two causes, one being that the lighting there is almost entirely in the hands of the big companies, who either hire out or supply the lamp direct, whether it is for street lighting or for stores lighting. I found

Mr. Patchell.

Type.	Watts.	Cost per 1,000-c.p. Hours.
		d.
Oriflamme	350	0·4
Weinert	350	0·55
Excello	470	0·57
Santoni	420	0·70
Open Arc	500	1·5
Enclosed Arc	500	2·0
Enclosed Midget Arc ...	250	3·0

Calculated from the data of the paper we find—Carbone, 1,000 watts and 1·0d. per 1,000 c.p. hours.

The figures are for mean spherical candle-power, and do not include carbons.

that the enclosed lamp was the favourite, due to the lesser labour it entails, as the enclosed lamp will burn a longer number of hours. They seem to appreciate this point highly, because one trimmer, they told me, could account for about 600 lamps, whereas in England, if on street lighting we can get one trimmer to do 40 lamps he is kept busy. Another reason for the flame arc lamp not being used there—and I had it confirmed in the last few days when I met the responsible engineer over here from one of the large American cities—is that they do not yet seem to know what high-pressure gas is! There are one or two hints that I should like to give the makers of flame arc lamps. Many that we have tried are, to put it shortly, not commercial, and of course electric lighting companies have to buy commercial lamps. Three out of four of the different types we have tried are, first of all, prohibitive in regard to the cost of carbons, and secondly, they will not burn long enough hours. That is a very important point for lighting companies, and it shows that the magazine arc lamp is the lamp that we will have to put our money into. When I first saw the internal arrangements of a magazine feed lamp, I was rather afraid that the effects of the gas and the fumes might be deleterious, but we have not found them to be so. We have run some of them now for a very long time, and have found the maintenance to be a mere bagatelle. There appears to be a prejudice against the yellow lamp, but that is only a question of getting the carbons made properly. We have had different shades from white to orange. I remember when I started arc lamps, twenty years ago, we used to get all sorts of colours, principally green or greenish, and that we knew next morning was due to the carbon-holders! On page 16

Mr. Patchell. the author states that the flickering cannot at present be entirely overcome in the chemical carbon lamps. My company's experience, after exhaustive tests with the oriflamme lamp, will not bear out that statement. We find that if the carbons are properly cored there is absolutely no flickering. I am bound to admit that there has been a little difficulty with the carbons, but you must not blame the lamp-maker for that. When we first had to buy ordinary carbons, we very often had them delivered with empty core holes! The ash given off is a little greater with the chemical carbon than with the pure carbon, but we have never found it enough to practically affect the efficiency of the lamp. As for the cost of the carbons, it is an important matter. Those that we are at present using cost 0·09 of a penny per lamp-hour, which is pretty close to the figure for ordinary arc lamps. The consumption of the Carbone lamp, as mentioned by Mr. Hoadley, is in the neighbourhood of 1,000 watts, and I quite agree with him that that is too high. There are certain cases where it can be used, but it is too high for general use. It is not stated in the paper whether the Carbone lamp can be made to consume less energy, but the chemical arc lamp most certainly can. The figures which I have just given above show that we had 350-watt lamps of several different makers running, and some of them are running particularly satisfactorily. It struck me that that is a great point in favour of the chemical arc lamp, and I am afraid it will take the pure carbon lamp people some time to catch up with the chemical arc lamp.

Mr. Cowan. Mr. E. W. Cowan: Some remarks have been made about the possibility of enclosing this type of lamp. I have experimented upon that point, and have succeeded in lengthening very considerably the life of the carbons by semi-enclosing. I have got a carbon life up to 53 hours with a pair of nine and seven millimetre carbons. I should say, however, that the enclosing of the arc tends to slightly decrease the steadiness of the light. There is a tendency with an inclined carbon lamp, when the arc is nearly enclosed, for the crater to change its position rather rapidly from one part of the carbon to another, and that induces a little flickering which, though it is not noticeable at a distance, Mr. Carbone, who wishes to keep to a very high standard in these lamps, objects to. I think probably Mr. Carbone will get over it, as he has told me that he had obtained a life of 300 hours, but he has not yet put that form of lamp on the market. With regard to some of the remarks made by Mr. Duddell as to the nature of the field which is used in this type of lamp, the lines of force are, I think, practically longitudinal between the poles. I do not know at all why it is that this particular form of magnetic blow-out or repulsion gives the shape of flame which is of such advantage in this lamp, but I think it may possibly be due to the fact that the arc is attracted or pulled out rather than repelled by the magnetic field. If you will refer to Fig. 4 you will see that the magnetic field will be more below the arc than above it. One cannot but see that there is a difference physically between an arc which is repelled and one which is attracted; and I think that perhaps the splaying out of the flame in the beautiful manner in which

it is splayed out in this type of lamp may be partly due to the field acting externally upon the arc rather than internally. There is one point which Mr. Andrews has not referred to in this paper. It appears to me that the higher voltage of the arc is not altogether thrown away, because there must be a larger amount of heat generated and consequently a tendency towards a higher temperature. I do not mean that the specific temperature of the crater itself will be any higher, but, as is well-known, the area of the crater is to some extent the measure of the temperature or of the conservation of heat; that is to say, if you allow cold air to come at all in contact with an arc the crater shrinks, and if you conserve the heat, as with the economiser or in other ways, the area of the crater enlarges, and therefore of course you get more illumination. I should quite expect, from the larger amount of heat generated within the cell of the economiser, that the crater will be larger with this type of lamp. Some questions have been asked as to whether it is possible to make this lamp in smaller sizes than 10 ampere and 850 watts. I have seen 160-watt lamps of this type and 7-ampere and 5-ampere lamps, and I know of no physical reason why there should not be smaller lamps. I think that the reason why those who have introduced this lamp in Germany have rather stuck to the larger lamp in the first instance is that they wish to compete with the chemical carbon lamp and to give as beautiful a display of light as possible. The 5-ampere lamp would be comparatively tame in its effect, and would not attract so much attention in influencing commercial operations in connection with the introduction of the new lamp. As regards the colour, I may say that, with Dr. Schwartz in Manchester, I have examined the spectrum of this lamp and compared it with the spectrum of such daylight as we get in Manchester, the two spectra being side by side. Neither Dr. Schwartz nor I could, on that occasion, detect the least difference between the spectrum of daylight and the spectrum of this lamp. We passed from band to band, and we could not detect any difference when comparing one with the other, so that I think we may take it that the light from this lamp is for practical purposes the exact equivalent of daylight. To my mind the point of chief importance in this paper is the case made out for the use of inclined carbons as compared with co-axial carbons. After working for a long time with this lamp, its æsthetic appearance strikes one as being so much better than that of the co-axial lamp, with its unavoidable shadows and unequal illumination of the globe, that one cannot help feeling that it really is a great step in advance of the co-axial lamp, and that the co-axial lamp is, in course of time, doomed to be only used in works and places of that sort where appearance is of no consequence. This virtue the chemical carbon lamp shares equally of course with the Carbone lamp. To my mind it is the globeful of light, whether it be white or whether it be yellow, which marks the great advance realised by this type of lamp. With enclosed lamps in which short carbons can be used, we can get an apparent globeful of light, because the specific illumination per square inch of the globe is so high that we are dazzled and cannot in consequence see the shadows; but if we look at the lamp through a Mr. Cowan.

Mr. Cowan. piece of smoked glass, we can see the shadows plainly enough, or if there is the least fog they become very conspicuous. The good effect is, however, only obtained at a very serious expense; that is to say, the eye is dazzled, the iris is contracted, and when we look at the objects illuminated—and it is not the idea of the arc lamp that we should look at the globe itself, but that we should look at the objects illuminated by it—when we look at those objects after taking our eyes away from the lamp, we find that they are apparently only half illuminated, owing to the contraction of the iris.

The Chairman. The CHAIRMAN (Mr. W. M. Mordey): There is no doubt as to the timeliness of the arrival of these long flame arc lamps. I remember, when Mr. Bailey gave us his excellent lecture on arc lamps at the Electrical Exhibition last year, he pointed out that this new arc lamp had arrived just as the ordinary arc lamp was being driven out by the serious competition of improved gas lamps. We have a good deal to thank gas companies and gas engineers for, and I hope we shall have more to thank them for. I hope the gas people will keep up their competition. It is only in that way that we shall make progress. Gas lighting is just as scientific as electric lighting—it is a case of give and take. Electrical engineers have taught gas engineers something, and the gas engineers in return have given us something. If it had not been for the gas-mantle we should not have had the Nernst lamp, and now we have got the flame arc lamp, which I think is coming in to keep the field for electric lighting for some time. But there is so much margin to be made up by one or the other or both of us that we cannot afford to rest on our oars yet. The real efficiency of even the best of these lamps is woefully low, and there is plenty of room for us and our descendants to get a reasonable return in light for the energy spent. A question has been asked as to the absorption of the globes. I think the best way to study that is to find an arc lamp with a broken globe, and then to look at the patch of ground lighted by the light coming through the hole, and then to look at all the rest. I do not think you will need any further evidence of the large absorption in ordinary globes. In giving a summary of his paper, the author was good enough to refer to a suggestion of mine in 1892, to use lamps with carbons arranged as they are now used in these long flame arc lamps, and with a magnetically deflected arc. There was not any novelty at that time in arranging carbons in a V form. Perhaps some of you remember that one of the early instances of arc lighting was with the Rapieff lamps at the *Times* offices, where inclined carbons were used—but I think not with a magnetic deflector. Then we all know the arc lighting by Jablochkoff with parallel carbons. Unfortunately for that lamp, the light was all thrown upwards. If Jablochkoff had applied the magnetic principle, and had deflected the light downwards, his lamps might be still in use. In my experiments in 1892 I was trying to improve lamps for projectors. One of the difficulties with projectors, especially for small boats, such as torpedo-boats, is the heating of the projector, and, of course, the size of the plant. I found an enormous improvement by deflecting the arc, and so letting the crater stare right into the reflector. I

remember having an ordinary 10-ampere lamp so arranged, and on looking at it from one end of the test-room, so that you could see the crater, it looked as brilliant as a 50-ampere lamp. I made a lot of experiments, but I came to grief over it, because I found that the long horn formed on the negative, and the deep crater on the positive, made it impossible to get a reasonably constant light in the projector. Then I started off on a series of experiments, rotating the two carbons slowly on their axes by a little electro-magnetic arrangement, in order to prevent the uneven horn and crater forming—to keep the crater and the negative tip always in the same position. But I never got any real success; it got to be too complicated. I still have a patent specification which I then wrote, but never filed! I therefore hardly think I am entitled to any credit for the mere suggestion to use inclined carbons with magnetic deflection. I would like to suggest to anyone who is interested in projector work that they should take up some experiments on some such lines—it might perhaps be found, with the improved carbons now obtainable, some useful result might be got for ordinary projector work—if, indeed, the work is not already done. The paper has interested me very much, for many reasons. I was glad to see, as an old advocate of alternate-current methods, the good showing of the alternate-current arc. My own experience was that, for a given amount of energy, the good result got by ordinary alternate-current arcs was largely due to the fact that in such arcs we get a longer arc with the same voltage than with direct current, and therefore the light gets out well. I was interested in the views expressed by the author as to the usefulness of the negative tip. You have only to deflect the arc so as to bring both tip and crater into full view to see that the negative area, although perhaps not as bright as the positive crater, has a very useful light-giving surface. It is rather curious that that should not have been recognised from the first. I remember some Siemens lamps at the Westminster Aquarium in very early days. Sir William Siemens apparently took it for granted that the negative carbon could not give any light at all, and therefore substituted for it a hollow copper rod, through which water was circulated to keep it cool. The light was entirely obtained from the positive crater. The Chairman.

Professor A. SCHWARTZ (*communicated*): Lighting engineers seem to be slowly awakening to the fact that in arranging a scheme of illumination for indoor or outdoor service there are other factors to be considered in connection with the lamps employed than the candle-power per watt. The questions of colour, steadiness, and suitable intrinsic brilliancy are beginning to receive attention, and our thanks are due to the author for the interesting manner in which he has dealt with these points. The consideration of vision is complicated by the fact that the problems presented are both physical and physiological, and, as lighting engineers are not much concerned with physiology, I may perhaps be pardoned for urging upon their serious consideration the following law enunciated by Fechner:—"Within very wide limits of brightness differences in the strength of light are equally distinct or appear equal in visual sensation if they form an equal fraction of the total quantity of light compared." That is to say, the distinctness Professor Schwartz.

Professor Schwartz.

of perception is not dependent upon the degree of illumination, but remains the same within wide limits provided the relative brightness of various parts of the picture remains unchanged.

A proper appreciation of the above law would have prevented the spectacular blazes of light in some of our metropolitan and provincial thoroughfares—such lavish illumination as 3-candle feet on a street surface is largely waste, as it does not enable us to see any better, particularly if the distribution is uneven.

In his consideration of lighting problems the author has appealed to two authorities—firstly to Nature, and secondly to the general public. Without wishing to disparage the latter, I would favour a reference to the former for guidance in such matters. From Nature we may learn, as the author points out in connection with the sun, that "radiants with high intrinsic brilliancy should be kept above the field of vision," and that if they come within the angle of sight their intrinsic brilliancy should be suitably reduced by diffusing screens. A second important deduction which the author has come near to making is that "all strong light should be directed upon us from above, and at a considerable angle to the horizontal." Nature has in our brows and eyelashes given us means of mitigating the effect of strong "top lighting," but that we are easily wounded by light directed upwards from the ground is evidenced by those whose eyes have been exposed for any time to sunlit snow or white road surface. We are but slightly better off with regard to strong horizontal light—*e.g.*, a motor lamp, searchlight, etc. With regard to the general public as judges of lighting, I am afraid they are usually inclined to favour a source of light which after a cursory glance causes the viewer to "see things" for some time after, being thus convinced from their experience in other directions of its undoubted potency. This prevalent notion should be strongly negatived, and anything "dazzling" should be considered as marking bad engineering. The gas companies have familiarised the public to the placing of lights within the field of view both for indoor and outdoor lighting. They began with a radiant of low intrinsic brilliancy, and by now adopting a radiant of much higher intrinsic brilliancy fixed at the same height have dazzled the public rather than illuminated them.

On the question of colour I should like to point out that the author's definition of "white light" is not quite correct, in that he assumes that daylight is constant in colour, whereas it varies very considerably from sunrise to sunset, only being white with a clear atmosphere about noon, and therefore a colour match made late in the day would not hold at noon even for daylight.

Of the close similarity of the spectrum from the Carbone lamp and that of daylight at noon I can bear testimony, and a further point in its favour is that its colour is constant, whereas with many chemical carbons of the concentric zone type the arc wanders from the impregnated zone, where the light is yellow, to the pure carbon zone, where the light is white, with unpleasant visual results.

Mr. Andrews.

Mr. LEONARD ANDREWS (*in reply*): Before replying to the points raised by the various speakers I would like to make a general remark

Mr. Andrews.

respecting a suggestion made by one speaker, that since the Carbone arc has received more attention than other flame arc lamps, it would have been more appropriate to have entitled the paper "Carbone Long Flame Arc Lamps." I purposely chose the broader title because I hoped that engineers who have had more experience than I have had with chemical carbon arcs would contribute some useful and interesting information *re* these latter arcs in the discussion, whereas, had the paper been limited to pure carbon arcs, any discussion on chemical carbon arcs might have been ruled out of order. I must say that I have been disappointed that those engineers who have developed these latter arcs have been so reticent in giving us any information thereon. The Carbone arc lamp was first brought to my notice when I was Borough Electrical Engineer at Hastings, and it struck me that it possessed some new physical features that I had not come across in any other lamp. It appeared to be so much of a departure from what had been previously written on arc lamps that it seemed worth while to bring it before this Institution for discussion. I don't think it can be said that I have made any claims for this lamp that makers of chemical lamps can take exception to, nor have I made any attempt to hide its defects. In the opening pages of the paper I have shown that on the question of efficiency only it cannot compare with the chemical carbon arc. On the other hand there are unquestionably other points, notably that of colour, in which the pure carbon arc is far ahead of the chemical carbon arc at present. Taking into consideration the fact that thousands upon thousands of arc lamps are used in this country alone, in positions where purity of colour is of even greater importance than efficiency, it is, I think, surprising to find to what a small extent the importance of a true discrimination of colours is appreciated by electrical engineers. Hitherto the very healthy competition between electricity and gas that has been referred to has centred round the question of m.h.s.c.p. per penny, and on this ground the chemical carbon lamp, as has been shown, has been more than able to hold its own against high pressure gas. But if electrical engineers are going to be so elated with this gain as to shut their eyes to the other equally important question, it is quite certain that gas engineers will not do so, and if they are able to produce an artificial light having the same spectrum as daylight, even though the efficiency expressed in c.p. per penny may be only half that of the chemical carbon lamp, gas burners will undoubtedly be largely used in positions that would have been held by electric lamps if the question of purity of colour had been considered alongside that of efficiency. I ought perhaps, in justice to Mr. Carbone, to have explained in my paper that he has always fully appreciated the great advantage of the use of chemical carbons from the point of view of c.p. per watt efficiency, and he is making a chemical carbon arc for use in positions where colour is of secondary importance, or where a yellow colour is preferred, that will, I believe, be found to compare favourably with other lamps of this type.

Mr. Trotter has questioned the reliability of the figures given in

Mr. Andrews.

Table I. The results given are so widely different for the respective types of lamps that I questioned them myself. I felt, however, that the first thing a practical man would look for in a paper on long flame arc lamps would be some information as to the saving effected by the use of chemical carbons. I was able to turn up some records of long flame photometric measurements which appeared to accord fairly well with each other and with theory, but I found it much more difficult to get reliable information respecting ordinary arcs. Thinking that Mrs. Ayrton's book on "The Electric Arc" would certainly give information on this point, I read it through from beginning to end, but could find no information either as to the maximum c.p. in any direction or as to the m.h.s.c.p. I then turned up Mr. Trotter's historical paper, and there found that he had apparently obtained less than 850 m.h.s.c.p. from a 26-ampere 50-volt lamp, or only 0·65 c.p. per watt. A comparison of this figure with the 2·24 c.p. per watt of the high-tension pure carbon arc and with the 5·8 c.p. per watt of the chemical carbon arc shows a far greater advantage in favour of long-flame arcs than I think has actually been obtained. I concluded, therefore, that some error must have been made in Mr. Trotter's measurements, and I consequently decided not to make use of this figure. Whilst the deductions given in Table II. may not be correct within 10 per cent., I think that they approximately represent the difference in efficiency between the various types of lamps referred to, and the results given by Mr. Patchell are, I think, an interesting confirmation of this table. Mr. Trotter also questions the figure I have taken for the intrinsic brilliancy of the crater, and he quoted one case where he had only got 64 c.p. per sq. mm. Mr. Trotter also gives this figure in his paper, to which I have referred above, and it puzzled me very much when I read it, but I concluded that it must have been the result of incorrect photometric measurement rather than an appreciable departure from what other experimenters give as the intrinsic brilliancy of the crater. Mr. Trotter draws attention to an error in the reproduction of Fig. 1, which was taken from his paper. I am afraid that this error crept in in the process of copying, and I had not noticed it because it did not deal with the point I wanted to bring out. My only object in using this diagram was to remind members that Mr. Trotter had shown what a very large percentage of light is absorbed by the negative carbon. I hope Mr. Trotter will accept my apology for this error. I was interested to hear that Mr. Trotter agrees that the colour of the chemical carbon arc is a very horrible one. He suggests that if the Carbone arc were compared with an ordinary arc lamp in broad daylight it would appear to be yellower. That is exactly the point I have tried to explain. The ordinary arc is generally admitted to be deficient in yellow rays and excessive in blue rays, and I have tried in my paper to give a reason why the ordinary arc is bluer than the Carbone arc, and consequently less yellow.

Mr. Harrison's contribution was very interesting, because it dealt with a point which I regret has not been discussed more, and that is the question of vertical *v.* horizontal lighting. Dr. Schwartz, of the

Manchester Technical School, has sent me a copy of a very interesting contribution he is sending to the *Journal*, dealing particularly with this subject. Mr. Harrison told us last week that what was wanted was horizontal light. I heard Mr. Harrison's very interesting paper before the Manchester section on this subject, in which he emphasised this point. He recommends the use of a reflector behind the light, to throw the rays out horizontally. Photometrically that is exactly what is wanted. But, as Dr. Schwartz points out, it is just the thing that is not wanted for practical use, because an observer will be blinded by the light streaming directly into his eyes. I think if we were to aim more at imitating nature and at getting the source of illumination as high up as possible, so that the light is thrown down, we should get a more even distribution of light without a blinding effect; and even although the illumination measured photometrically may be less, the general effect will be a great deal better. Flame lamps, either chemical or pure carbon, have great advantages for this purpose, because they throw the bulk of their light down, whereas the ordinary arc lamp throws most of its light out at an angle of 40 or 50 degrees. I noticed in Berlin that one of the squares was illuminated by two or three chemical carbon lamps hung on a pole which was probably 50 ft. or 60 ft. high. The effect was very fine indeed. Mr. Andrews.

A MEMBER: Have you seen the very high mast at Bournemouth? A Member.

MR. ANDREWS: Yes. The Bournemouth mast was, I believe, made by the Brush Company a good many years ago for the Glasgow Exhibition, but they used ordinary arc lamps, and consequently directly round the post it was comparatively dark. If flame lamps were hung from this mast I think the effect would be greatly improved; it is true the result will be what Mr. Harrison told us the other day is not wanted, namely, a bright light directly underneath the arcs, but my own view is the public do like that. I am of the opinion that there is no serious objection to the illumination directly under the arc being several times greater than it is mid-way between arcs so long as the direction of the rays is not such as to be blinding. Mr. Harrison's chief object appears to be to get a photometric measurement between the lamps as nearly as possible the same as it is directly underneath the lamps. This result can be quite simply attained by the use of projectors, but the effect upon persons walking towards the source of light is disastrous, as they are unable to see anything except the dazzling light ahead of them. Returning to the question of what has been termed "patchy illumination," I would remind you that on a bright, sunshiny day the illumination in the open is many times that in the shade, yet no one would suggest that, since the illumination in the open is more than is actually needed, this should be reduced by screening to what it is in the shade. My opinion is that so long as we provide sufficient illumination mid-way between lamps for all purposes, it does not matter how much more than is actually necessary we get directly below the lamps, and the public like a bright effect directly below the lamps, just as they like bright patches of sunlight. Mr. Andrews.

Mr. Andrews.

Fig. 23 has been referred to by several speakers. I merely gave that figure as an illustration of the point which I have just been trying to make. By fixing either chemical carbon or pure carbon flame lamps very high up in the way proposed, and using unobscured globes, you can get the effect which is really wanted—that is, a strong light on the ground which is not blinding. Mr. Harrison and other speakers asked what area is supposed to be illuminated by the various arrangements of lamps shown in Fig. 23 and Fig. 24. This is quite immaterial as I pointed out on page 18 of my paper. The relative distribution will be the same so long as the height of the lamps is increased proportionately to the distance between lamps. Let us assume, for instance, that the problem to be considered is that of lighting tennis or badminton courts covering an area of 200 ft. by 200 ft., and that the minimum permissible illumination is 0·5 candle ft. For this purpose, 35 460-watt enclosed lamps placed 30 ft. high would be required, whereas four 800-watt flame lamps placed 75 ft. high would be ample. The maximum illumination directly under the flame lamps would be 0·75 candle ft., and the minimum illumination midway between lamps would be 0·55 candle ft. The illumination taken is the combined illumination on the surface of the ground from all sources. This is, I believe, the usual method of measuring illumination, and when the light rays are chiefly vertical it appears the only reasonable method. When the rays are projected horizontally the illumination should, as Mr. Harrison points out, be measured in one direction only. It may be objected that some difficulty would be experienced in supporting lamps 75 ft. above the ground. It appears to me, however, that a simple way of doing this, in the case referred to above, would be to support the lamps from small captive balloons. Mr. Duddell has asked what I mean by the soft core of a carbon. I can only say that I am quoting Mrs. Ayrton. When I started on this paper I knew very little about arc lamps: consequently I read Mrs. Ayrton's book right through, and I saw a number of very interesting references to the difference between the soft core crater and the hard carbon crater arc; one difference referred to being that a longer arc can be produced across soft core carbons than across hard carbons. When I saw the photographs which are reproduced in Figs. 7 and 13, I thought they were an interesting illustration of Mrs. Ayrton's experiments. Mr. Duddell suggests that the two arcs shown in Figs. 7 and 13 are burning intermittently, and not simultaneously in parallel. This had not occurred to me before, but I think Mr. Duddell is probably right. The photograph was taken with a hand camera, the instantaneous shutter being adjusted to give the shortest possible exposure. There would, however, probably be ample time for the arc to change from the soft core to the hard carbon during the exposure, this giving the appearance of arcs burning in parallel. I repeated the experiment several times, and took a large number of photographs, but always found that at that voltage I got the effect of two arcs in parallel. Mr. Duddell also raised the question of absorption of the mist, and asked what I knew about it. I do not know anything about it beyond what

Mrs. Ayrton has told us. I think Mrs. Ayrton is fairly convincing, as she gives tables showing that with an ordinary arc lamp if you increase the pressure and expose more crater you do not increase the light; and she deduces from this that the increased light due to the larger area of crater is swallowed up in the mist. Until someone gives some other reason for it, I think we must accept Mrs. Ayrton's explanation as the most feasible one. The only test I have been able to make of mist absorption—perhaps it can hardly be called a test—is the deduction from the curves shown in Fig. 18. Inasmuch as the total theoretical light is only a small amount more than that actually obtained by photometric measurements, it appears to me reasonable to assume that the absorption by the mist with this formation of flame is very small. Mr. Cowan has dealt with the question of the shape of the field, resulting from the Carbone magnetic control. Mr. Duddell questions the meaning of the slant of the records reproduced in Fig. 25. I am afraid I cannot endorse his opinion that it is due to so interesting a cause as he suggests. I may be wrong, but my impression is that the slant is due to the fact that the two craters were not absolutely parallel to the axis of the moving drum carrying the sensitised paper, and, therefore, one crater has the appearance of leading a little in advance of the other. Mr. Gaster asked if I had made any experiments to determine to what extent the fumes were poisonous. I only made one, and that was quite enough for me. I was trying an experiment one day with a chemical carbon lamp in a rather small room, and, although I was only at it for an hour or so, I had such a splitting headache for the rest of the day that I concluded I had been poisoned. Mr. Gaster tells us that if we will only specify what colour is wanted, makers of chemical carbon arcs can give us any colour we like. I have attempted to give a definition in the paper of what I consider to be the true meaning of white light. The so-called white light of some impregnated carbons I have seen does not resemble this in the remotest degree, and from all I have been able to learn, I understand that chemical carbons suitable for colour discrimination have not yet been made. Please understand that I do not think that is the colour we want for all purposes, and I quite agree with some of the speakers that for many purposes the yellow colour is preferable even to white; but, as Mr. Hoadley has told us, there are a number of places where it is important that colours should appear the same when lighted by artificial light as when lighted by daylight. It has been suggested that the blue ribbon which I showed last week looked better under the chemical carbon lamp than it did under the pure carbon arc. That may be so, but again that is not my point. It is not a case of what looks best under different lights. The experiment referred to was simply made to show that the colours did not look the same. If a lady selects under the light of a chemical carbon lamp a material for morning wear that she believes to be a sea-green, and she finds, when she comes out into the daylight, that it is a bright blue, I think she has a just cause for complaint. Mr. Mordey has made the reply I was going to make to Mr. Gaster *re* the absorption of light by opalescent globes. When I

Mr. Andrews

Mr. Andrews.

was at Hastings I often got into trouble if an arc lamp globe was broken, because my committee used to say, "How inefficiently the cleaners clean those globes; you can see at once that 75 per cent. of the light is being absorbed by the dirty glass." But it was not dirty glass; it was simply the ordinary obscured glass. Mr. Eck has criticised me for introducing the figure of candle power per ampere into Table II. I have explained the reason why I have done so in the paper. I think all central station engineers have experienced that there are many cases where a tradesman only wants two lamps, and if he only uses two lamps on a 200-volt circuit, and his lamps only take 50 volts each, the remaining hundred volts is absorbed in resistances and represents so much wasted energy. This wasted energy ought to be considered as part of the wattage consumed by the lamp. I maintain, therefore, that it is at times quite as important to know the current consumption per candle power as the watts per candle power. Mr. Eck describes a method of avoiding this waste by a combination of inside and outside lighting. The positions in which such a combination could be effected with any advantage are, in my opinion, few and far between. Complications are at best involved which can be entirely avoided by using either an enclosed arc or a high-tension pure carbon arc. Mr. Eck asks whether there is any appreciable air circulation in the flame of the Carbone arc. I am inclined to think that there is not, and that the peculiar shape of the flame tends to exclude air from the crater. He referred to some experiments made some years ago to ascertain if screening the crater tended to enlarge it. I also remember references to experiments which consisted of blowing on the crater and thereby cooling it. Those experiments clearly showed that the area of the crater was diminished when cooled. It appears, therefore, as Mr. Cowan has suggested, that if the flame does keep the cold air from contact with the crater, this alone should tend to give somewhat higher efficiency. Mr. Eck questions the efficiency of alternating flame arc lamps. I forget exactly where I saw Dr. Wedding's results, but I think it was in *Science Abstracts*. The results referred to experiments with flame chemical carbon arc lamps. My point was that the increased efficiency was mainly due to the use of downward-feeding carbons. Mr. Eck asked if I had noticed what was the effect of twenty-five periods upon the eye. In looking at the arc itself, the alternations are distinctly noticeable, but when reading a paper underneath the arc, it is very difficult to say whether the flickering is perceptible or not. It is certainly nothing like so perceptible as it is with coaxially arranged carbons. I think the fact that in a flame arc the craters are alternately at a maximum and simultaneously visible explains why that is so. Mr. Hoadley mentioned that 300-watt lamps were badly wanted. I quite agree that this is so, and indeed there is very little demand for a 10-ampere 800-watt lamp, but, so far, I have been unable to get the smaller wattage lamps in this country. The inventor has, however, promised that he will very soon be able to send over some 400-watt lamps. Two or three speakers have asked what carbons were used in making the various tests of the Carbone lamp which are quoted in the paper. Dr.

Wedding in his report upon these tests makes a great point of the fact that ordinary commercial pure carbons were used for his tests. Mr. Hoadley raised the question of the possibility of enclosing chemical carbon lamps. I think it would be almost impossible to so enclose such arcs as to appreciably increase their hours of burning. Mr. Patchell's news respecting the result of the competition between gas and electric light at Charing Cross Station is very welcome. The figures he gives showing the relative cost of electric lighting by different types of arcs are very useful, and I am interested to note that these figures of cost per 1,000 c.p. obtained from actual experiment appear to confirm the theoretical deductions given in Table II. of the paper. I agree with Mr. Patchell that for street lighting a chemical carbon lamp has advantages over a pure carbon arc. Mr. Mordey has referred to the usefulness of the negative light. I was also surprised to find what a lot of light one gets from the negative. I noticed when developing the photographs that the negative crater appeared practically simultaneously with the positive crater, from which I conclude that the intrinsic brilliancy of the respective craters is practically the same in each case. Mr. Andrews.

The CHAIRMAN: Judging by your applause, gentlemen, I think I may conclude that you will very willingly pass a vote of thanks to the author for the paper he has given us, which has not only been a very useful paper in itself, but has led to a very interesting and useful discussion. The Chairman.

The resolution was carried by acclamation.

Proceedings of the Four Hundred and Forty-second Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 10, 1906—Mr. W. M. Mordey, Vice-President, in the Chair.

The minutes of the Ordinary General Meeting held on Thursday, April 26, 1906, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associates to that of Associate Members—

E. J. McLeod. | F. J. Edgar.
W. H. N. James.

From the class of Students to that of Associate Members—

J. O. McLaren. | J. E. Roberts.

Messrs. C. K. Falkenstein and V. A. Fynn were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

John Alexander Thomas Barnes.
John Stennitt Bean.
David Henry Boyd.
Harold Hodgkinson Broughton.
William Howard Brown.
Albert Bernard Clark.
Victor Ambrose Cornelius.
Jens Ludvig Diemer-Hansen.
Frederick Downes.
Richard Bertram Leach.
George Phillip Lee.
Arthur Mears.
Godfrey Henry Emile Muller.
John Hampden Parker.
Samuel Robert Pearce.
Andrew Robb.
George Edward John Smith.
Edgar Everett Stark.
George Cecil Walsh.
Amos Lawrence Weekes.

As Associate.

Lucius Augustus Kingston.

As Students.

George Martin Carrie. | Walter Frank Higgs.
Percy David Williams.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Constable & Co., Ltd., H. Borns, The Royal Observatory, Greenwich, A. H. Stanley, The Director-General of Posts and Telegraphs, Holland, The National Physical Laboratory, G. D. A. Parr, R. T. Glazebrook; to the *Building Fund* from Mr. S. Evershed; and to the *Benevolent Fund* from The Robertson Electric Lamps, Ltd., to whom the thanks of the meeting were duly accorded

The discussion on Mr. L. Andrews's paper was concluded (see page 29) and the meeting adjourned at 9.30 p.m.

LEEDS LOCAL SECTION.

WASTE IN INCANDESCENT ELECTRIC LIGHTING, AND SOME SUGGESTED REMEDIES.

By GEO. WILKINSON, Member.

(*Paper read February* 15, 1906.)

The supply of electricity for lighting purposes is, and must remain the backbone of business, so far as most electric generating works are concerned, and the loss of the lighting load would, in many instances, mean closing the works, while to stations supplying mainly electrical energy for power purposes, the loss of their lighting load would probably have the effect of raising the cost of operation to such an extent as to more than fill the margin of economy which electric power has over rival methods of power distribution.

During the last few years many improvements have been made in arc lamps; their already high efficiency has been increased, while first cost and cost of operation have been so reduced that their field of application has widened and their use is likely to extend largely; nevertheless, the major portion of electric lighting is, and will continue to be, carried out by means of incandescent electric lamps, of which probably over 95 per cent. are carbon filament lamps, the small percentage remaining being made up of Nernst, tantalum, osmium, and incandescent vapour lamps.

Every enterprising station engineer, in order to secure a healthy growth of business against increasing competition, diligently seeks to reduce his cost of production and distribution. Labour-saving appliances—such as fuel and flue gas testing instruments, superheaters, improved forms of steam and electric generators, better methods of conversion and distribution, together with a more intelligent idea as to the effect of load and diversity factors—have done much towards reducing these costs (allowing a corresponding decrease in the tariff charges to consumers), and yet, finality in this direction, even with our present methods and knowledge, still lies some distance in the future.

The average prices obtained per unit in Great Britain (omitting exclusively tramway undertakings) during 1904 and 1905, were as follows:—

	Year ending March, 1904.	Year ending March, 1905.
Limited Liability Undertakings... ...	4·26d.	4·06d.
Municipal Undertakings	3·08d.	3·02d.

Points Relating to Waste and Extravagance.

It is when we get beyond the meter fixed on consumers' premises, which marks the boundary of the supply undertakers' authority and jurisdiction, that waste and extravagance take place.

This is mainly due to the use of incorrectly graded and inefficient lamps, and the persistent use of lamps after they have become blackened on the inner surface of the glass bulb.

So marked is this lamentable waste, and its effect upon the future of electric lighting is so serious, that it is high time some definitely concerted action was taken by the supply authorities throughout the country to deal effectively with the matter, and to educate every consumer so that he may know how to get efficient electric lighting at a reasonable cost.

Electrical engineers have too long considered themselves simply producers and purveyors of electrical energy, and have not concerned themselves with the problem of turning a minimum amount of electrical energy into a maximum of lighting power, the consequence being that many a user is paying for double the amount of electrical energy for lighting he ought to pay, and not a few lucrative electric light consumers have, regardless of health considerations, gone back to the use of gas.

Gas companies have not been slow in taking advantage of our carelessness in this matter ; they recognise that their customers want a good light on a minimum consumption of gas. This they insure for them by installing in their showrooms the most efficient gas lighting appliances, and by taking steps to make such appliances known to gas consumers ; also they take good care to imitate electric lighting as closely as possible in their design and arrangements of fittings. The effect of this enterprising policy is to be seen in most towns, especially in the business quarters, where numbers of shops which a short time ago were illuminated exclusively by electric glow lamps are now mainly lit by the incandescent gas mantle ; the front window show-cases being alone reserved to the electric lamp, partly to give an air of superiority to the establishment, and, chiefly, to avoid steaming of the windows and the risk of fire to the closely packed goods. Thus the long hour lamps go to the gas company's credit, and the short hour unprofitable lighting to the electrical undertakers.

A similar undesirable process is going on in private residences, especially of the smaller class, where, for economy, the kitchen and back portions of the house are given over to the unhealthy gas mantle or oil lamp, the front hall and entertaining rooms being reserved to the electric glow lamp.

To show an urgent need for attention on the part of engineers to the points raised, I set forth a few of the many cases which have come under my personal notice during the last few months.

(*a*) *Public Building.*—Eighty 32-c.p. British-made 100-volt lamps, taking an average of 170 watts each. The light in this case was exceedingly unsatisfactory, owing to drop in pressure, and by putting

in 16-c.p. lamps certified by the Corporation (as hereinafter explained), the light was improved and the current consumption very greatly reduced.

(*b*) *Private House.*—Consumer using 8-c.p. British-made lamps, giving in one case only 2·1 c.p. at 11 watts per candle, and another 3·2 c.p. at 8 watts per candle ; also one 16 c.p. giving 8·9 c.p. at 6·6 watts per candle.

(*c*) Four special 16-c.p. 200-volt foreign lamps, sent for test, dropped from 16 c.p. to 7 in less than 100 hours. These might have been used on consumers' premises with disastrous results.

(*d*) *Private House.*—Consumer found to be using 230-volt lamps on a 200-volt circuit.

(*e*) *Private House.*—Consumer found to be using $2\frac{1}{2}$ c.p. lamps taking 30 watts each, or 12 watts per nominal candle at 200 volts. Actual c.p. given by the lamps was 5 on photometric test.

(*f*) *Shop.*—Nominal 8-c.p. lamps, giving 5·5 c.p. and taking 6·6 watts per candle.

The following cases have been given to me by engineers of other electrical undertakings :—

In the public buildings of a large city in Scotland, the British-made lamps, from a number of tests made, were found to be taking an average of 8·29 watts per mean horizontal c.p., and 9·14 watts per mean horizontal c.p. in the case of Continental-made lamps.

Investigations made in a leading manufacturing city in Yorkshire show an average of 7·6 watts per mean horizontal c.p. in the case of foreign lamps, and 7·03 watts per mean horizontal c.p. in the case of British-made lamps. Tests made on 8 and 16 c.p. lamps in stock, in the same city, showed a variation of from 2·98 to 5·67 watts per mean horizontal candle.

Investigations in one of the chief cities in Lancashire on new 16-c.p. lamps held in stock by the Corporation showed a variation of from 3·25 to 8 watts per candle, with a variation in c.p. on standard voltage from $10\frac{1}{4}$ to 20 candles.

I do not suggest that the lamps in all the above-cited cases are necessarily bad lamps, but they are certainly wrongly graded and marked. These are only a few instances, and I am convinced that in many towns the cost of electric lighting is greatly increased to the consumer, due to errors in the grading and marking of lamps. So far as I can ascertain it appears to be the general practice amongst lamp-makers to sell lamps marked with a nominal c.p. but actually giving considerably less than that marked on the bulbs.

Suggested Remedies.

Legislative.—Clause No. 18 of the 1882 Electric Lighting Act should be immediately abolished, and a new clause substituted, giving the electricity supply undertakers right of supervision over the lamps used on their supply mains, and the right to refuse to supply customers using wasteful lamps. In my view this desirable supervision can be exercised without the undertakers taking the lamp trade from the local

contractors: such a step on the part of municipalities would be an unwarrantable and unfair interference with the business of private tradesmen in the district.

The assumption of the lamp trade by the electricity supply undertakers would mean a serious loss of business to all the local firms, and in numbers of cases the local tradesman would be compelled to close his business through lack of trade, as the lamp supply business is to the local contracting electrical engineers very much what the repairing business is to the boot and shoe seller: if they cannot retain it, their business would no longer be remunerative, and the district would soon be minus the class of persons who are the best canvassers for the electric supply business, and who do the canvassing free of charge to the undertakers.

Local Precaution.—I have, in co-operation with the local contractors in Harrogate, developed a system of control over the lamps used on the supply mains which, while it secures to the Corporation the control referred to, leaves the contractors the benefit of their trade in lamps, and puts no restriction upon them as to what make or class of lamp they supply to their customers.

It is desirable that we should have legal powers to compel contractors to supply, exclusively, lamps approved by the supply authority: at present we are able to get a written undertaking only, and depend upon the contractors to abide thereby honourably; in Harrogate, such undertaking appears to be quite sufficient, at present, to effect what we want.

Lamp Specification.—Twelve months ago I drew out a specification which was issued to all lamp manufacturers supplying lamps to the district, with the intimation that in future lamps would not be certified for use on the Harrogate supply mains which did not come within the specification, both as to candle-power and wattage. The result of the specification was that many grosses of lamps of all makes were returned to the manufacturers from Harrogate.

Considerable feeling was manifested on the part of several manufacturers, due to the constant refusal of lamps; now, however, they appear to have settled down to comply with our requirements, and very few lamps which are now sent for certification fail to pass the required tests, and the consumer has already begun to feel the benefit of their improved efficiency. We have numbers of instances where the accounts have decreased since certified lamps were used, and the ultimate result is bound to be an increase of business accruing to the Electricity Department.

Notices to the Consumers.—A notice is attached to the quarterly account calling the attention of the consumer to the importance of using, exclusively, lamps certified by the supply authority, and warning him against buying lamps from casual travellers.

Municipal Electrical Association.

The question of the efficiency and grading of lamps has been recently taken up by the Municipal Electrical Association, and a more

comprehensive and detailed specification has been drawn up; but its issue to the members of the Association is postponed at the request of the Physical Standards Sub-Committee of the Engineering Standards Committee, and the Municipal Electrical Association has elected Mr. C. D. Taite and myself as their representatives on this sub-committee. This committee have gone into the question of lamp efficiency and grading in great detail; have had careful tests carried out by various lamp manufacturers, and have held an all-day conference with the representatives of the manufacturers, and their deliberations are now approaching completion. Doubtless the effect of the Municipal Electrical Association's recommendations, when issued, will be beneficial to all parties concerned, and especially to the consumers. It is difficult, however, to see how the full benefit of these proceedings can be felt until Clause 18 of the 1882 Electric Lighting Act is annulled or modified. It is to be hoped that concerted action will at once be taken by the supply undertakers in this direction.

Drop in Candle-Power and Life Tests.—It is usual in ordering lamps from manufacturers to specify the maximum drop in candle-power allowable after the lamps have been on circuit a stated number of hours at the standard voltage marked upon the lamps.

The specification generally fixes a maximum of 20 per cent. drop in candle-power on a 400 or 600 hours' run. In making this test a maximum rise in pressure of 2 per cent. should be allowed, as closer regulation is not obtained on public supply mains.

A difficulty presents itself in the length of time required to verify the drop in candle-power; very few makers or dealers will consent, or can afford, to lay large stocks of lamps aside for five or six weeks while drop in candle-power and life tests are being made on sample lamps drawn from each consignment; the consequence is that these important tests are almost entirely neglected, and in the writer's opinion large numbers of lamps are continually put on circuit which blacken prematurely and bring discredit upon the industry. Experiments which I have made show that a very thin film of deposit on the internal surface of the glass bulb serves to reduce the light by 50 per cent., and a lamp loses two-thirds of its original candle-power before it gets to the condition commonly accepted as "black."

The lamp merchants should rigidly insist upon the makers submitting a percentage of each batch of lamps to an independent and recognised authority for drop in candle-power test; such lamps being selected promiscuously from the bulk; and the maker should furnish a certificate setting forth the results of such tests.

A life test is not nearly so important as the drop in candle-power test, and lamps which show good results on candle-power after the specified number of hours may generally be accepted as satisfactory on the score of durability.

It is better to use lamps with large glass bulbs, as the internal blackening process is thus spread over a greater area, and is therefore thinner, presenting less obstruction to the light. This view is confirmed by the rapidly increasing use of lamps with large spherical bulbs, which

do not reveal the blackening process nearly as quickly as the ordinary sized glass bulbs.

It is of great practical importance that drop in candle-power tests should be considerably shortened by employing a pressure higher than the standard working pressure for, say, 150 to 200 hours; this will decrease the expense and inconvenience of keeping back lamps during the weeks at present absorbed in making these tests.

Fortunately the time can be shortened to about 150 hours by applying a slightly increased uniform pressure, but this method at present is followed by only one or two British firms; it is, however, common in America, and will doubtless become regulation practice everywhere in the near future.

Equipment of Local Lamp-Testing Room.—The large numbers of lamps which are likely to be submitted for test in all local centres where lamp supervision and certification is adopted and the small charge which can be made per lamp (½d. in the case of Harrogate), necessitate expeditious methods, giving reliable results. The writer has experimented in many directions and with many instruments before arriving at a fairly expeditious, reliable, and simple method, employing current derived from the ordinary supply mains. The equipment is as follows:—

Wattage Measurements.—The method employed entails the use of a standard voltmeter and a small hand-regulated booster (or sliding resistance in the case of direct currents), by means of which the volts are adjusted to and maintained at the exact pressure marked upon the lamps. After the pressure adjustment is made each lamp is in turn inserted into a lamp-holder connected with a standardised dead-beat wattmeter, the resultant reading in each case being recorded in ink pencil upon the brass cap of the lamp. They are then placed in light baskets and passed on to the photometer. Any lamps falling outside the specified wattage limits are placed on one side for return as unsatisfactory.

Photometric Measurements.—The photometer scale consists of a wooden bar 2¾ ins. wide by ½ in., set on edge and mounted upon a 2-in. by ¾-in. horizontal base, which projects on each side of the scale carrying bar and forms a runway for the standard lamp-holder, the lamp-holder for lamps under test and the intervening spot box, all of which are mounted upon wheels and are furnished with screw clamps to secure them in any required position upon the scale bar.

The scale is of varnished paper glued upon the face of the scale bar, and graduated on each side of a zero line in the centre of the bar, directly in candle values, so that the illuminating power of any lamp can be read off at once without calculation of any kind; the scale is an open one, and is graduated up to 70 candles on each side of the zero centre line.

The photometer head is of the ordinary grease-spot type, provided with screens so that the operator's eyes are shielded from the glare of the light standard and lamp under test. It is permanently clamped at the zero mark on the photometer bar. In cases where lights of different colours are being compared a flicker head is substituted.

The light standard is placed and securely clamped on the left of the spot box in such a position on the scale as to give an 8, 16, 32 c.p., or other definite illuminating value upon one side of the grease spot.

The lamp under test is placed in a lamp-holder upon a moving carriage on the other half of the scale, this holder being rotated at about 200 revolutions a minute by means of a small motor and worm gear carried on the moving carriage and controlled by a switch near the operator.

A standard voltmeter with illuminated dial is placed immediately over the photometer head, and a small booster adjusted by a screw motion (or sliding resistance in the case of direct currents) is located under the bench carrying the photometer, so that the operator can with facility maintain the exact standard electrical pressure.

Standard of Light.—I strongly condemn the general use of pentane or any other flame standard; they are very difficult to manage, and vary in illuminating effect from time to time, according to atmospheric and other conditions. Good pentane is difficult to obtain, still more difficult to keep, and it is expensive. Ordinary incandescent lamps which have been "aged" until their illuminating power becomes stable should be selected and sent to the National Physical Laboratory to be standardised at a declared voltage, and the position in which they are standardised should be carefully marked upon the glass bulb near the cap.

These lamps then form reliable standards of reference, from which substandards can readily be obtained for use on the photometer by the lamp-testing assistant; thus the original standards, being little used, do duty for a long period and seldom require re-standardising.

The operator in the photometer-room has his lamps already marked for wattage on the caps, as before explained, and after a little practice he is able to take the photometric values very quickly; he is then in possession of all the data to enable him to determine if the lamp complies with the specification.

Lamps which pass are placed apart from those which fail to pass, and they are finally stamped upon the glass bulb by means of a rubber stamp and etching fluid with the word "CERTIFIED" and the initials or crest of the authority certifying same. This stamping operation is accelerated by slightly warming the lamp bulb in a spirit lamp before the stamp is applied. The equipment described is not expensive, and it is not too delicate for a youth of ordinary intelligence to use.

The average rate of testing, including every operation, is about four dozen lamps per hour, and there appears to be no good reason why in regular work the rate should not be increased to six dozen per hour.

PRESSURE REGULATION.

It is little if any use insisting on manufacturers supplying more efficient incandescent lamps unless some serious effort is made to maintain a uniform pressure upon the electricity supply mains. The present low average efficiency is, at least in some measure, the result of bad pressure regulation on the supply network, which is destructive to high efficiency lamps, causing premature blackening on the inner surface

of the glass bulbs and shortening the useful life of the lamps. Many lighting circuits are unfit to supply any lamps of higher efficiency than "traction" lamps, while numbers of supply networks are badly laid out, and so stinted of copper that it is necessary to maintain abnormal pressure at the feeding centres during heavy loads in order to produce a satisfactory light in the remote districts.

Lamp manufacturers, in guaranteeing the number of hours a lamp will operate before the candle-power drops 20 per cent. of its initial candle-power, stipulate that the voltage of supply shall be kept within narrow limits, difficult to realise in practice, but, inasmuch as a small increase in pressure greatly accelerates the blackening of the lamp bulbs, an approximately uniform pressure should be continuously maintained by some type of automatic apparatus; the too common practice of trusting to hand regulation should be abandoned, as it is at best both spasmodic and unreliable.

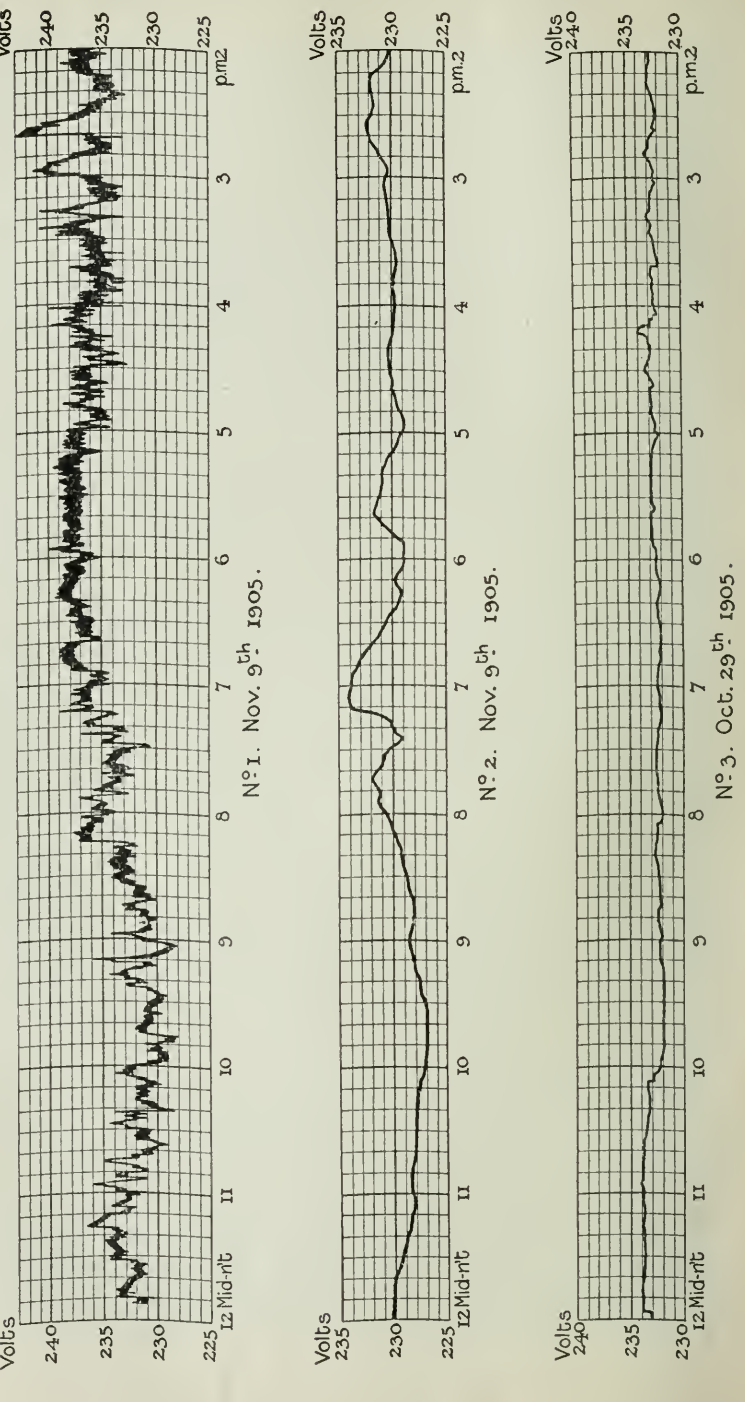
The following pressure diagrams are exact reproductions from the pressure recorder charts of ten of the most important towns and cities in Yorkshire, five having a direct current and five an alternating supply. Nos. 2, 3 and 4 of the direct-current stations, and No. 3 of the alternating current stations, carry a traction load in addition to the lighting load.

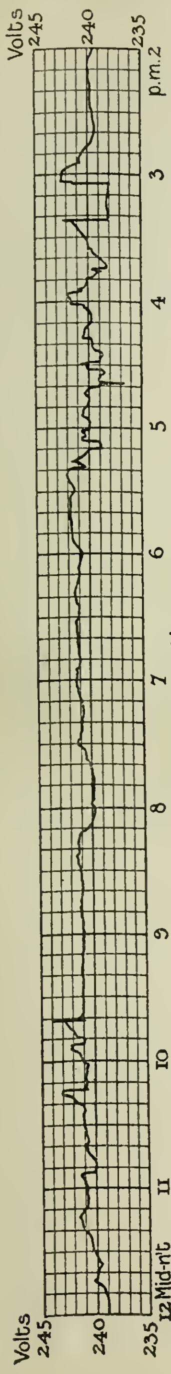
I am not at liberty to name the towns where these pressure charts were produced, excepting No. 5 of the alternating-current charts, which is an ordinary chart taken in the centre of the distribution system in Harrogate, and its uniformity is secured by the use of automatic pressure regulators at the generating works. Many of the charts show very irregular pressure regulation; the direct-current stations are the worst sinners in this respect, and, in my opinion, the first step towards obtaining more efficient and economical electric lighting must be taken by the station engineers themselves by greatly improving their pressure regulation, and until this is done it is useless to call for more economical lamps. Doubtless, recently obtained motive-power loads which are supplied from the lighting distribution mains have in some instances rendered the already unsteady pressure much worse, and to sacrifice the steady pressure necessary for good lighting in order to pick up a few motors is questionable policy. Circuits for the supply of power should be separate from those supplying light, where the fluctuations due to varying and erratic power load have a prejudicial effect upon the lighting.

Regard should be paid to the fact that carbon filaments have a negative characteristic, *i.e.*, the higher the temperature the less their resistance, and until filaments having a positive characteristic come into general use, uniform electrical pressure for lighting must remain a factor of prime importance.

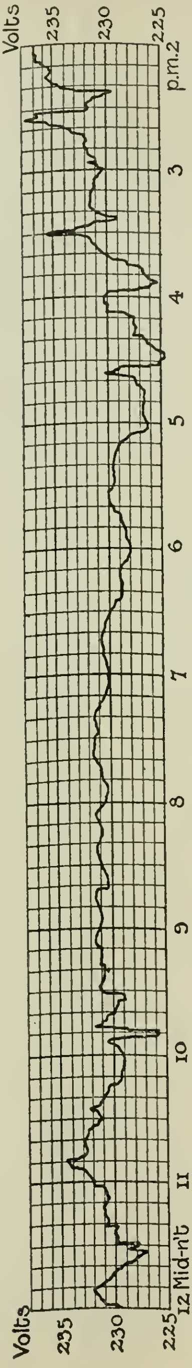
Modification of System.—The system of testing and certification outlined in this paper is suitable for districts in which there is a large number of small consumers who purchase their lamps in small lots from local dealers. Large users who buy thousands of lamps at a time would probably be satisfied by having a certain number of lamps tested

DIRECT CURRENT STATIONS



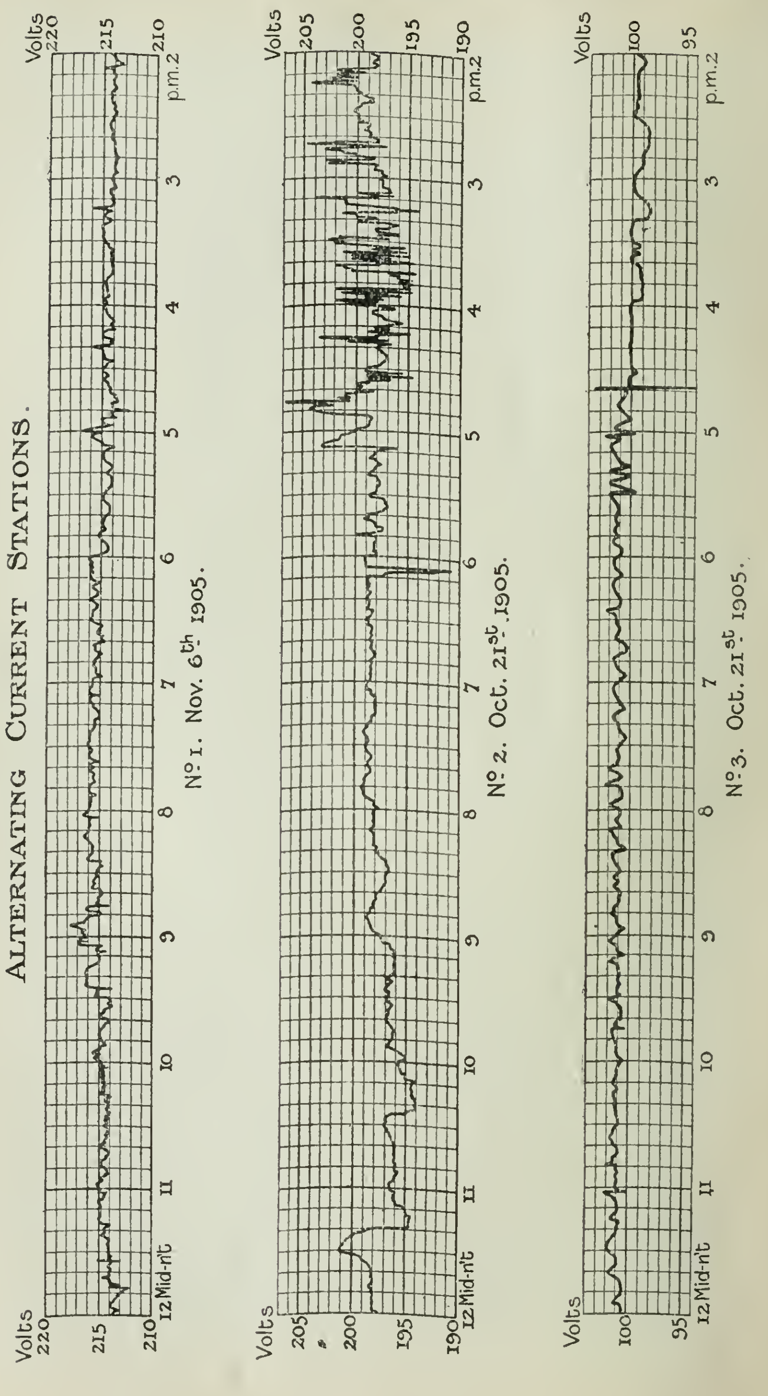


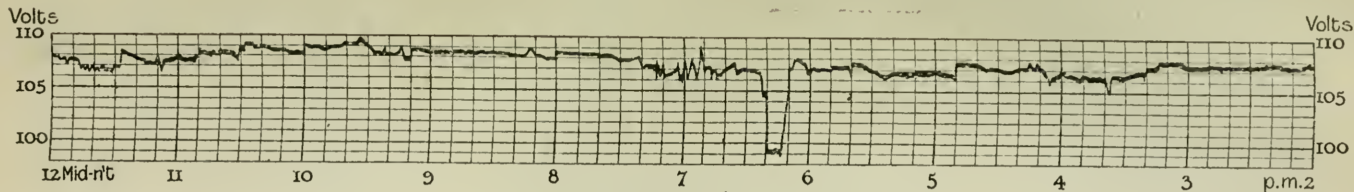
No. 4. Nov. 19th 1905.



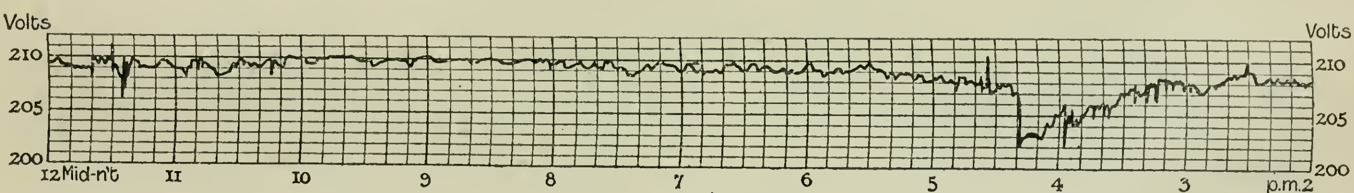
No. 5. Nov. 21st 1905.

Alternating Current Stations.





Nº 4. Sept. 8th 1905.



Nº 5. Nov. 4th 1905.

NOTE.—Current for Electric Traction is also supplied from Direct Current Stations Nos. 2, 3 and 4, and from Alternating Current Stations.

out of each consignment received, the acceptance of the bulk being contingent upon the tested lamps turning out satisfactory.

Before concluding, I desire to mention a few other types of incandescent electric lamps which are coming into active competition with carbon filament lamps: of these the best known and largest used is the:—

Nernst Lamp.—The experience of engineers with this type of lamp is very conflicting; some appear to get satisfactory and economical results, others complain of rapid fall in candle-power and short life of filament. It would be interesting in the latter cases to examine the pressure charts—the Nernst lamp, notwithstanding the steadying effect of the wire compensator, is very sensitive to fluctuations of voltage; economical and good average duration of candle-power and life can only be obtained on steady voltage. The manufacturers state that on direct-current circuits it is important that regard should be paid to polarity, while numbers of users state polarity may be disregarded, provided the polarity is not changed after the lamp is once placed on circuit. Again, it is stated that the filaments should be run for at least twelve to sixteen hours when first put on circuit, in order that the filament may get into a stable condition, and lamps which survive this preliminary run are likely to have a life of satisfactory duration; it would be interesting to know how far these statements are confirmed by extended experience. The question whether the lamps last better on alternating or direct current circuits is one on which there are strong but divided opinions, and very little, if any, reliable evidence.

I have found the burners last well on both direct and alternating current circuits, but in each instance automatic pressure regulators are used, which keep the voltage variation within 2 per cent. In street lamps the average has been close on 500 hours per burner. For street lighting the 'B' and 'D' type of burner are of very little use, as they cannot be depended upon to light up on a cold or stormy night, due to the filaments being below the heaters; also the heaters are particularly frail and liable to break. The 'A' type lamps, on the other hand, will light up within a minute on the coldest night, and the 100-watt 'A' type filament, due to its superior conformation, gives approximately 30 per cent. more light on the roadway than the 100-watt 'D' type burner, which has a 'U' shaped filament. 'A' type lamps are, however, expensive, and the writer has adapted the 'A' type burner to the 'D' type body, whereby the cost is reduced to less than half that of the 'A' type lamp, while the lighting efficiency of the 'A' type lamp is obtained. This has been recognised by the Nernst lamp manufacturers, who are now arranging to put a lamp of this type on the market, which for convenience I have designated the 'AD' type.

The 'AD' type lamp put into clear, well-shaped glasses and supplied with current at 1d. per unit is in successful competition with the gas mantle for street lighting in several towns, and its use in this way will doubtless rapidly increase in the near future.

By careful photometric measurements I find the Nernst lamps, in clear globes, give a greater amount of light *pro rata* on the amount

of electrical energy than "Midget" arc lamps furnish; probably on a time test, however, the Nernst lamp would fall in candle-power to a greater extent than the arc lamp.

Nernst lamps—especially the 'B' and 'D' types—are badly designed from a light-giving point of view; the opaline globes—especially the pear-shaped pattern—obstruct a great amount of light, and there is no means of placing a reflector in an effective position.

Recognising this, I designed and patented the modifications shown in the accompanying illustration (Fig. 1), and obtained thereby a wonderfully improved lighting effect, with the diffuser and reflector, as compared with the ordinary alabastrine pear-shaped globe.

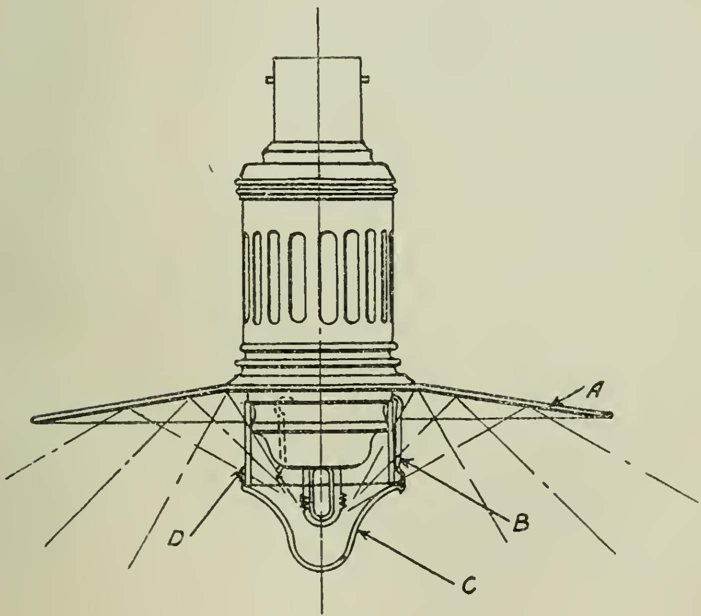


FIG. 1.

A. Opal reflector.
B. Three-pronged clip attached to ring supporting reflector and carried by three hangers.
C. Opal cup clipped by three prongs termed "diffuser."
D. Clear glass cylinder termed "draught excluder."

The following results were certified by Mr. Lancelot Wild on behalf of the Westminster Electrical Testing Laboratories to have been obtained :—

	Candle-Power.	
Angle below the horizontal.	With Diffuser.	With Globe.
0 degrees	19·5	29·0
10 "	26·0	31·0
20 "	32·5	32·0
30 "	38·5	31·0

Angle below the horizontal.	Candle-Power. With Diffuser.	Candle-Power. With Globe.
40 degrees	44·0	29·0
50 "	48·5	26·5
60 "	52·5	24·0
70 "	55·5	21·5
80 "	58·5	19·0
90 "	60·5	17·0
Mean hemispherical candle-power ...	38·6	29·0
Watts: 51·2 at 200 volts	...	...
Watts per mean hemispherical candle-power	1·325	1·76

It will be seen from the above figures that below the angle of 20 degrees from the horizontal, which includes all the useful lighting area, the mean spherical candle-power shows an efficiency of one candle per watt, a result unapproached by any other electric lamp of small candle-power.

Vacuum Tube Lighting.—Some good examples of this system of lighting can be seen operating in business premises along Broadway, New York, notably at the office of the *New York World*, which is illuminated by one tube 86 ft. long, running round the office and fixed beneath the ceiling cornice: lighting tubes of this class are in operation up to 155 ft. long. They are operated by extra high-pressure alternating current, ranging from 5,000 volts upwards, produced by a transformer enclosed in an earthed metal box; the light produced is soft and agreeable, and is a near imitation of daylight; the intensity of light can be regulated from a faint glow to twenty or more candles per foot of tube, which tubes are about 1¾ ins. diameter. The illuminated tube can be looked at without inconvenience to the eye, and it appears as though it were a long cylinder of densely white smoke. The light radiating from such a large surface area gives a very perfect diffusion, and a practically "shadowless light" result. No mercury is used in these tubes, and the makers claim an efficiency as high as 1½ watts per candle, including transformer loss, and state that the life of the tubes is "almost unlimited."

Very little information is available about this form of lighting; I cannot find that there are any of these lamps in Great Britain, but the American examples are strikingly effective, and the method is worthy of more attention than it obtains at present. Probably the ultimate form of electric lighting will be by means of incandescent vapour, of which the well-known mercury vapour lamp forms an unsatisfactory and crude example.

DISCUSSION.

Mr. Campion.

Mr. R. H. Campion: I quite agree with the author that the use of badly graded lamps is one of the drawbacks to the present lighting system. I know of a case where 200-volt lamps were put on a 220-volt

circuit, and for some considerable time we were unable to get at the cause of the amount of current used until we cleaned the lamps and found that underneath the label they were marked 200 volts. Another fault is the astonishing amount of slackness in design and arrangement shown by wiring contractors and architects when the installing takes place. It appears that Mr. Wilkinson has found quite a number of bad lamps in his tests. Personally I had no idea there were such bad lamps as 6·6 watts per candle. I think the supply undertakers will have to take this matter into very serious consideration. In some cases I know of, contractors are charging as much as 50 per cent. more than cost for the lamps. I think that if some system such as they have at Bradford, of giving lamps as discount, was adopted, it would improve matters considerably. The prices for repairs charged by contractors are so excessive that we shall very seriously have to take up the idea of installation work. With reference to the raising of the pressure for quicker candle-power drop tests, the increase will blacken the lamps, and then a decreased candle-power will be obtained. I do not think any town can afford to lay down separate mains for power consumers. I would like to know the limit in variation of pressure with 220-volt lamps, in order to retain a decent light. I am of opinion that lamp makers have not improved this at all. Mr. Campion.

Mr. W. B. Woodhouse: I am of opinion that with the competition which supply undertakings have with gas and other forms of illumination we must develop improved lamps, and we must also study the consumer. Improvements in the station are not as necessary as in consumers' installations, and we must remember, in fact, that we are selling light, not current. I agree with Mr. Wilkinson that the wiring contractor is a valuable canvasser, and should be encouraged. Mr. Wilkinson's system of insuring good lamps to the consumers is excellent; there are other ways of doing this, one system being to change all the consumers' lamps every six months and supply new ones; those taken out are tested for wattage and candle-power, and those that do not come within certain limits are destroyed, while the others are returned to stock, ready to be sent out again. The cost of doing this can be included in the price per unit charged for current. On the subject of lamp testing I would like to ask the lamp-makers whether conclusions drawn from ageing and wattage tests, at pressures above the normal, can be depended on. Mr. Wilkinson suggests ageing lamps at 50 per cent. above their rated pressure, and, if the tests made after such accelerated ageing can be relied on, much time will be saved. The author's pressure charts are most instructive. I think that the Harrogate chart speaks well for the lay-out of the network and for the automatic regulator used at the station. Mr. Woodhouse.

Mr. A. S. Blackman: As is generally known, free lamps are supplied in Bradford, and, after two years' experience in working the system, I certainly think it is one of the very best things that have been done in the way of looking at the problem from the consumers' point of view. We have been distributing about 14,000 lamps per annum, and the cost of supplying them amounts to less than 3 per cent. of the Mr. Blackman.

Mr. Blackman.

consumers' bill. This can be looked upon as a discount of 3 per cent., and it is rather interesting to note that, previous to the free-lamp scheme, the consumer had a discount of 2½ per cent. allowed for prompt payment, but the free-lamp system was found to insure this very much better than the giving of discount, from which it can be inferred that the consumer appreciates it very much more than a corresponding reduction in his account. We have found from experience that a man feels it a good deal more when he loses his lamps than his discount. There is nothing at all to say against the free-lamp system, and, in my opinion, it is very much more preferable than the registration at the cost of ½d. per lamp, as suggested in the paper. I am very much surprised at the voltage curves submitted. At the time Mr. Wilkinson asked for the Bradford curve we were running on temporary switch-gear, and had very limited means of giving a satisfactory supply. This voltage chart was sent on to Mr. Wilkinson with apologies on its behalf owing to the circumstances. To my surprise, on receiving a copy of this paper, I found that it was the steadiest voltage curve that Mr. Wilkinson had obtained, but matters have been very much improved at Bradford since that chart was submitted. On the new switchboard each of the low-tension feeders is provided with a recording log which gives a continuous record of the amperes passing through the feeder and the volts at the feeding-point, and in that way an automatic load curve for each feeding area is obtained daily. Since the districts have been split up the results are much better than what is represented on the voltage chart in the paper, and they are certainly not so good yet as those we expect to get in the near future, when some ten extra low-tension feeders will be put into commission. The curve shown was taken on a network with close upon 6,000 B.H.P. motors connected to it. It would be too serious to curtail this load for regulation purposes. We have no automatic means of regulation. I prefer a good switchboard attendant to any automatic device. A clerk goes over each record with a rubber stamp and marks the name of the charge engineer for each eight-hour shift during the twenty-four hours; the records are put up in the engine-room, and everything is done to encourage keen competition between the men having the supervision of the switchboard attendants, and we find this a very good scheme. (Mr. Wilkinson: "Do the Bradford Corporation take any measurements of the candle-power and the voltage of the lamps?") "Yes, and I can perhaps amplify that point by saying that we now divide our lamp contracts among the principal English makers, so that a consumer can have any well-known lamp which he may desire, on application."

Mr. Churton

Mr. T. H. Churton: I hope that the suggestion of multiplying the already too numerous voltages in use will not be adopted. With regard to the cost of domestic lighting, a considerable amount of current is wasted by lights being left turned on when not required. Electric lighting, with current at usual rates, can be made relatively economical when reasonably economised by lights being turned off when not in use. Respecting the size of lamps, I agree that lamps with large globes

would probably take longer to blacken than would lamps with smaller globes; but, unfortunately, large globes do not lend themselves readily to artistic effects, and this consideration demands a compromise. Where appearances are much considered, lamps with comparatively small bulbs will usually be preferred. With regard to the suggestion that consumers should be obliged to adopt certain makes of lamps, I quite agree with Mr. Dickinson that this would be decidedly inexpedient and contrary to one's ideas of freedom; besides, one's motives would be open to misconstruction. With regard to raising the voltage of the lamps, supposing that a 190-volt lamp is used on 200-volt circuit, a greater amount of light is obtained, but the "life" of the lamp is much shorter; and the question as to whether this will be economical clearly depends upon the cost of the current; the dearer the current the more it will pay to get the most out of it, though the lamp renewals cost more. In some places where the cost of current is low it would pay to use lamps of low efficiency, and thereby obtain long life for the lamps; but where the price is relatively high it will pay better to run the lamps at a high efficiency, and thus reduce the electricity bill. Mr. Churton.

Mr. HOWELL: It seemed to be the impression that the condition of affairs shown by Mr. Wilkinson is entirely the fault of the lamp-makers. As soon as the conditions are such that consumers know and appreciate exactly what lamps are, the results will be different. It is rather unfair to say that all the improvements in lamps must be made by the maker, without the aid of the valuable assistance that can be rendered by the supply station engineers. What is wanted is the help of the lamp users, and Mr. Wilkinson's efforts in this direction are worthy of praise. The lack of information on the part of the general user is regrettable. In the United Kingdom at the present time there are about one million k.w. of plant laid down, of which about six hundred thousand k.w. are used for private lighting only, and the way in which lamps are used, and the average indifference of the user produce a most unsatisfactory condition of affairs. If the supply station engineers would co-operate with the lamp-makers towards improving the methods of using lamps, the quality of the lamp would improve. In the use of high efficiency lamps a steady operating voltage is of primary importance, and it can be shown that if lamps are operated on a voltage that is constantly 4 per cent. high (the limit of the B.O.T. regulation), the life of the lamp would be reduced from 100 per cent. at normal voltage to 44 per cent. This reduction in life is a matter that is not fully appreciated. As regards the shortening of the life of lamps on test, there seems to be a difference of opinion on that question at the present time, but I know the life of a lamp on test can be shortened by burning it at some *higher efficiency* than that for which it was made. There is a definite relation between the watts per candle-power and the life of lamps, and the hotter the lamp is run the shorter its life will be. This relation was determined as far back as 1883, and in 1888 figures were obtained and published on the old types of carbon lamps then in use, and these figures are approximately correct, within certain limits, for all types of ordinary carbon filament Mr. Howell.

Mr. Howell. lamps manufactured at the present day. I consider that if one lamp is 10 per cent. better than another at an efficiency of 2·5 watts per candle-power, it would be 10 per cent. better at 4 watts per candle, or at any other efficiency.

Mr. Dickinson. Mr. H. Dickinson: With reference to the keen competition with incandescent gas, there is no doubt in my mind that this is a serious matter. It is beginning in Leeds, and some people are taking out electric lamps from the inside of the shops whilst still keeping the shop windows lit. Something will have to be done to check this, but it remains to find out the best method. If the lamps are kept in good condition, and the pressure regulation is perfect, it will help matters very materially. The author mentions a public building with eighty 32-c.p. 100-volt lamps taking an average of 170 watts each. I do not know whether that is an odd instance or whether the author means that there are many such cases. I have obtained a lot of figures, and I cannot find anything of a similar nature in Leeds. None of them vary more than a few per cent., so that I think that it cannot be taken as a general occurrence. With regard to other instances mentioned, *e.g.*, lamps of $2\frac{1}{2}$ c.p. giving 11 watts per candle: since reading the paper I have sent a man round to pick out some lamps, about a dozen from different installations, and I have had them tested. The worst ones showed 4·99 watts per candle, whilst some of them were down to 3·5 and 3·6. Some of them certainly looked black, but I think the author has overdrawn the case a little. I believe I could go into an installation and find a lamp as stated, but it would be from a position where the light is of little moment—where, for instance, so long as there is a light that light is sufficient. Look at the lamps in the shop windows in Leeds, where a light is wanted, and I think you will find that they are very well looked after. In the middle of page 54, tests are given on 8 and 16 c.p. lamps taken from stock, and they show a variation of from 2·98 to 5·67 watts per candle, which is very peculiar and surely only a special case. With regard to the suggested remedies, it may be advisable to have Clause 18 of the 1882 Electric Lighting Acts altered, but I do not think it will come about. I do not think there is any precedent to allow the undertaker to specify the type of lamp the consumer shall use. In the case of the gas department, however, they cannot specify what kind of burner they are to use, or even select the form of taps for the water consumers in the water department. It is a very good suggestion to test the lamps, and if the wiring contractors will not do what the undertakers require, we shall have to educate the consumer. If we find that the contractors are putting in their own lamps, we shall have to take more trouble to educate the consumer to buy fully tested lamps. I should like to ask if the author has made any tests to see what difference there is in his standard testing apparatus when the lamp is revolving and when it is stationary. I do not agree with Mr. Wilkinson in respect of the different circuits, as it is entirely out of the question to think of laying separate mains for lighting and power. I have always tried to buy machines of good regulation and transformers with a low drop, in

order to keep the pressure as uniform as possible. With regard to the Nernst lamp I would have been very glad if the author had told us something more definite. The consumers like them on account of the saving on their bills, but there is a lot of trouble with them, and I do not think the fault is due so much to pressure regulation as to some faults of the lamp which the makers have not got over. Mr. Dickinson.

Mr. C. WILSON: In reading Mr. Wilkinson's paper the first important thing that struck me was the opening sentence—"That the supply of electricity for lighting purposes is almost the backbone of the electrical generating business." It would appear from the little attention which has been given until recently to the improvements in general lighting that this has not been the opinion of all central station engineers. It is very fortunate for the trade as a whole that the general matter of lighting, particularly the efficiency of lamps, has been brought so much to the front, first by the sub-committee of the Engineering Standards Committee, and subsequently by various papers which have been read, including those by Mr. Gaster at the Society of Arts, the present paper, and others. Speaking from the manufacturers' side, I am not quite so sure that the question of grading lamps can be settled in the way which you gentlemen and the Standards Committee anticipate. It is an unfortunate fact, but it is true, that up to the present no lamp-maker has been found who can make lamps for a given voltage and guarantee that all the lamps will turn out to this particular voltage when finished. This necessarily means that every lamp-maker must have a number of outfalls which do not come into the voltages for which they were intended. If engineers issue specifications with narrower limits than those existing at the present time, they must bear in mind that this necessarily means that the price of lamps will go up instead of down, and that they will thus put into the hands of the gas companies a very great advantage, for, after all, the consumer does not look so much at the total on his bill at the end of the quarter as to the amount he is repeatedly called upon to pay for his lamps, and a rise in the price of lamps would have a very bad effect upon the trade. In studying this matter it has often struck me that the American system of grading voltages is far superior in every way to the one existing at the present time in England. We have in our factory a very large proportion of orders for, say, 200-volt and 220-volt lamps; we execute these orders, and we have left on our hands out of both classes a number of lamps which would come into, say, the 210-volt class. For these lamps we have no demand. What are we to do with them? If we break them up somebody must pay the cost of manufacture; this, of course, means the consumer. If we do not break them up they remain in stock as useless, and the same argument applies. The Standards Committee propose to standardise the voltages at 220 volts, allowing a 10 per cent. margin on either side. Mr. Wilkinson states in his paper that it is possible to keep his voltage within 2 per cent. What difficulty would there be in the way of supply engineers arranging to have a different voltage in each town, the greater number to have, say, 220 volts or 110 volts, and varying on Mr. Wilson.

Mr. Wilson. each side in steps of, say, 5 volts. By proportioning the number of stations with each voltage to suit the lamp-makers you would not interfere with the standardising of your motors and other apparatus which you require, but it would certainly help the lamp-makers in grading their lamps, and in helping the lamp manufacturers to do this you would do yourselves a service. If you do this, we, as manufacturers, would undertake to supply you with a more efficient lamp—a lamp which is graded nearer than even Mr. Wilkinson or the Standards Committee are asking for at the present time; and I know that by grading your voltage you would assist the manufacturers to keep down their stock of outfalls, and thus finally you would cheapen the lamps to the consumers. I have had the opportunity of twice visiting the United States, principally with regard to the lamp business, and there is no doubt that the system which they adopt there, in grading their voltage to suit the output of the lamp factories, is an excellent one, both from the central station engineers' and from the manufacturers' points of view, and it cannot be denied that the lamps supplied in America are far more closely graded than the lamps supplied here, owing to the advantageous conditions under which they work. It may be within the knowledge of most of you that the central stations in America are closely allied to, and work hand in hand with, the lamp manufacturer, and if it is found in their lamp works that they have a percentage of outfalls for which there is no demand, in the next central station which is put down the voltage is graded to suit that particular line. It would be of great advantage if the central station engineers of this country were to consult more with the lamp-makers on such points as these, as, after all, the electric lamp, with the exception of arc light carbons, is the only article of consumption in connection with electric lighting, and is the article which the consumer must buy repeatedly, and the expenditure for which is drawn mostly to his attention. It seems to me that there will be no difficulty in arranging that a standard voltage should be set up, and that, say, 60 per cent. of the stations be run at this standard voltage and the other 40 per cent. be graded below and above in steps of, say, 4 or 5 volts. Mr. Wilkinson mentions the question of bad results of varying pressure, but he has not mentioned that where the voltage is considerably over-run the consumer has to pay for this increase and gets less satisfaction from his lamps. A nominal 200-volt circuit run at, say, 206, which is not uncommon, would increase the consumers' bill from 4 to 5 per cent., and the poor contractor who is asked to state the exact amount the prospective consumer will have to pay bases his figures on those supplied by the lamp-makers as to the watt consumption of their lamps, but when the bill comes in and the consumer has to pay the extra percentage he naturally grumbles. This is quite apart from the question of shortening of life and the rapid blackening of the lamp. It may interest you to know that if you take a nominal $3\frac{3}{4}$-watt lamp and over-run it—

2	per cent.	it becomes a	3·5-watt	lamp.
4	„	„	3·3	„
6	„	„	3·0	„

Mr. Wilson

Whilst on the question of blackening it may be said that the figures given by Mr. Wilkinson as to the 50 per cent. deterioration of c.p. are quite correct, provided the lamp is absolutely black. I have recently made some tests on this particular point—for this purpose we obtained a number of lamps from consumers which they termed black, and according to the density of the blackening, the results show from 15 per cent. to 40 per cent. loss in candle-power. On page 54 Mr. Wilkinson gives some sample figures of the watt consumption of various lamps which he has found, but one can hardly believe that any British maker would knowingly send out lamps of this description, more especially the 32 c.p. Evidently the 32-c.p. lamp which Mr. Wilkinson tested was originally 50 c.p., and supplied in error. The total wattage of a 32-c.p. lamp should not exceed from 110 to 120 watts. With regard to the other variations in watts mentioned by Mr. Wilkinson, I do not mind admitting that we, as lamp manufacturers, have at various times—and I know that other makers have done the same—supplied for circuits which we have known to be continuously over-run some less efficient lamp than we should have supplied had we known the circuit to be run at the normal voltage. If these lamps supplied had been tested at the normal voltage then there is no doubt that the candle-power would have appeared too low. A further great question which remains practically in the hands of the central station engineer is to educate the consumer to the fact that the lamp which burns the longest hours is not necessarily the cheapest lamp. It is a fault which must be laid entirely on the station engineer that the general public believe, even to-day, that the lamp must be made to last 1,000 hours. We have tried for some considerable time to induce people to believe that the higher efficiency lamp at the prevailing price of current would be the cheapest lamp to burn, but, being in the unfortunate position of lamp-makers, we have been looked upon with great suspicion, as the consumer would probably have to buy two or even three lamps in the place of one, but by this means the consumer would save money. However, the recommendation coming from a lamp-maker, makes the consumer, who does not understand, suspect the lamp-maker of pushing his own interests. On the question of high voltage lamps, one of the greatest difficulties of the lamp-maker has been the fact that in change-over operations, when the low voltage was used, lamps were supplied in very small bulbs, frequently, say, 40 to 45 mm. diameter, and crinkled lamps were also supplied in small bulbs. During the change-over operation the consumer naturally expects to get higher voltage lamps made in these extraordinary bulbs. It was some years before we could induce contractors and others to persuade their customers that these small bulbs would not be satisfactory. Even so recently as the Marylebone change-over, there has been a demand for 240-volt lamps in these small bulbs, and there has been a great deal of trouble in connection with them. Consumers should be educated to the fact that they cannot get high voltage lamps in the same small bulbs as previously supplied for low voltage. With reference to the photometric standards mentioned by Mr. Wilkinson, we have

Mr. Wilson. supplied for some years a large bulb with aged filaments for primary standards, and secondary standards are usually calibrated from this for general use. In conclusion, I would like to urge upon central station engineers that closer co-operation between the manufacturers of lamps and themselves would be a very great advantage generally, and if the result of the time and trouble expended by Mr. Wilkinson and other gentlemen in preparing their interesting papers only results in any form of closer co-operation, the trouble these gentlemen have taken will not have been in vain.

Mr. Emmott. Mr. W. EMMOTT: Too little attention has been paid to the consumer in the past, and it would be well to follow the example of the gas industry, where the consumer is treated with the care and attention found in other commercial undertakings. Exhibitions, permanent showrooms, and advice on gas-consuming appliances are at the service of the customer of the gas undertaking. I strongly advocate something of this nature in electricity undertakings, and I emphasise the fact that, if the electricity department of a municipality is to hold its own, the resident engineers will have to adopt Mr. Wilkinson's plan and commercialise their departments more in the future than has been the case in the past. I have had a large number of tests made somewhat on the lines indicated by Mr. Wilkinson for some time, and generally I agree with his results, although I have few so bad as the worst recorded in the paper; they were, in my experience, the exception and not the rule. Consumers require educating, and I have found that it pays to do that; they are ready to fall in with reasonable suggestions as to getting the best lamps, weeding out the bad ones, and keeping the lamps and shades reasonably clean. Many good lamps lose 15 per cent. of their illuminating power simply through an accumulation of dust.

Mr. Hartnell. Mr. W. HARTNELL: With regard to the very bad lamps, if they have been tested as 16 c.p. and all at the same voltage as the satisfactory lamps, that might account for the bad result. If Mr. Wilkinson had tested them on the voltage that best suited each individual lamp he would probably have found very little difference in the watts per candle. With reference to the point mentioned by Mr. Dickinson, I hold that the consumer had a perfect right to do as he pleased. On the other hand, it is very desirable to point out to him the benefits which accrue from using good lamps. In Leeds, some manufacturers are buying lamps in hundreds and are paying 8d. or 9d. each. In one large factory, where they have at least 2,000 lamps, the engineer in charge tests the lamps in his own way. In three-light pendants he will put the lamps of three different makers. On a 110-volt circuit he uses 105-volt lamps, and directly they begin to show signs of dulness he throws them away and replaces them with new ones, so that this consumer does what the station engineer would advise. With regard to the Corporation supplying lamps, I see no objection to that, providing it is done at a profit on the business lines of a private concern. Regarding the suggested graduated differences of standard voltages in different towns, that might be most convenient for makers

of lamps, but what about the makers of motors? It would be very awkward for them. Mr. Hartnell.

Mr. P. ROSLING: For real economy in lighting, the cost of candle-power hours should be compared rather than the price per unit, especially where people are reasonable and consider their electricity bill equally with their lamp bill. Taking current at 4d. per unit and lamps at 1s. each, and allowing for the increased candle-power and decreased life, over-running the lamps 1 per cent. would decrease the yearly cost 3 per cent. for the same candle-power as compared with normal running, and by over-running them 5 per cent. the cost per candle-power hour would be decreased 12 per cent. I do not think there would be any objection to Mr. Wilson's suggestion of varying voltage at different stations, from the motor point of view, as, for continuous-current work, we already have to face a larger variation than proposed, viz., 200 to 250 volts, with almost every multiple of 5 in between, and it will usually be found that for well-designed alternating-current motors on ordinary supply circuits, 5 per cent. above or below the standard voltage will not affect their satisfactory operation, providing they are fairly liberally rated; motors designed for 210 volts should be quite satisfactory on 200- or 220-volt circuits, and this variation, coupled with direct-current stations and private supply variation, should give lamp-makers sufficient margin. The voltage curves given on the diagram are exceedingly good, but I presume they are taken at the centre of supply; from my own experience I regret that lamps have very much more to put up with than appears evident from the curves; on the network, especially when a good way out from the centre, I have known the pressure vary from 10 per cent. below to 10 per cent. above the normal in the space of half an hour. I am confident that Mr. Wilkinson's curve of pressure will help even on the extreme edge of the supply area, as it is certain that the peaks at the station have a cumulative effect on certain feeders, as the pressure may be high at the centre while the load on one feeder is particularly light, and *vice versa*. Mr. Rosling.

Mr. W. M. ROGERSON: With reference to the remarks of Mr. Wilson and the grading of the lamps, I think it a very good plan indeed. I agree with Mr. Rosling that 5 or 10 per cent. difference in the pressure has no serious effect on the motor. In Halifax motors are running for various purposes fed from the tramway feeders, and occasionally the variation exceeds 15 volts with no serious effects to the consumer. Mr. Rogerson.

Mr. G. H. CORRINGHAM: With regard to the legislation part of the paper, I would like to say that Clause 18 of the 1882 Electric Lighting Act does not lay down any new law, but is merely declaratory of the common law or rights of persons. There is no chance of it being done away with, and the desired legislation on Mr. Wilkinson's part is a state of affairs which he will never see realised. When consumers purchase any commodity they can do as they please with it, so long as they do not interfere with any other person by so doing. With reference to the comparison of the small arc lamp with the Nernst lamp, I would like Mr. Wilkinson to say how the arc was enclosed, and in what kind Mr. Corringham.

Mr. Corringham. of globe. He states that the Nernst lamp was in a clear globe. With regard to the average cost per unit for local authorities and companies, if that average cost has been obtained, as I surmise it has, by the addition of all the average costs in the table divided by the number of average costs, it is not correct unless the author has taken into consideration the various outputs attached to the various costs. I would have liked the author to have said a few words about the tantalum lamps, because I believe his experience has been better than that of most engineers.

Mr. Acland. Mr. R. L. Acland (*communicated*): I am fully in accord with Mr. Wilkinson's plea for greater attention to be paid to the subject of incandescent lamps by station engineers and others controlling the supply of electricity, for it is of very little use to procure the highest possible efficiency in the station, by various means, if the consumer, from whom the revenue comes, is left entirely to his own devices, or to obtain such information as he can from the local contractor. Personally I have always spent a large amount of time looking after our various consumers, whether they be the owners of big establishments or of small shops using half a dozen lamps, and, with a view to educating them to the better use of the incandescent lamp, I have recently instituted a system somewhat on the lines of Mr. Wilkinson's arrangements for lamp testing. I drew up and issued to the whole of our consumers a card of hints as to how they should use their incandescent lamps, at the same time telling them that we would test any or all of their lamps at the works, free of charge, only returning to them such lamps as were fit for further use. During the two months this has been in operation some 2,000 lamps have been dealt with, among which have been found many samples quite as bad as those quoted by Mr. Wilkinson. We also sell lamps at a reasonable margin of profit.

Mr. Fedden. Mr. S. E. Fedden (*communicated*): The figures given on page 53 show that it is beneficial to the consumer when the undertaking is in the hands of the municipality. The author has given us some startling cases on page 54, but I cannot help thinking there is some mistake. He speaks of eighty 32-c.p. lamps taking 170 watts each. Surely 120 watts would be more nearly correct! The author advocates the sale of consuming devices and apparatus by gas companies, but thinks that electric supply departments should not sell lamps. Why this inconsistency? The presence of a "live" wiring and fittings department would go far to prevent the occurrence of cases such as those mentioned. I am not convinced that lamp selling is the mainstay of an electrical contractor's business; it certainly is not in the case of the Sheffield Corporation, where the lamp sales amount to less than 7 per cent. of the business. I have been in the habit, for some time, of fixing notices to consumers' accounts recommending them to use only the best lamps, but I have not yet established a system of certification. Of course, all lamps purchased and sold by the Corporation are supplied to a specification, and tests are carried out on a certain number of lamps from each consignment. I agree with the author when he says that closer regulation than 2 per cent. is not obtained on

supply mains. It is not by any means obtained, as the curves show. Supply authorities in England often follow the practice of "applying a slightly increased uniform pressure"—unwillingly, of course. I should like to ask the author if there is any law, connecting rise in pressure and blackening, which would make it possible to take life tests in a few hours, or days? Definite information on this point would be valuable. The photometer in use at Sheffield resembles the author's in most particulars, except that I use a pentane standard, and move the photometer head instead of the lamp under test. I believe, however, that the author's method has certain advantages over mine. The author should also bear in mind that automatic apparatus prevents fluctuation, but cannot level the pressure all over the network. It is not financially possible to use separate circuits for power and light, to say nothing of the increased complexity of the system which would result. Referring to Nernst lamps, my experience of them has not, up to the present, been satisfactory. The only burner which has lasted any length of time has been one fitted with the author's diffuser, and it has occurred to me that the freer access obtained by the air to the filament has perhaps contributed to its longer life. Mr. Fedden.

Mr. H. L. P. Boot (*communicated*): Mr. Wilkinson brings home, in a very practical manner, the fact that the major portion of the waste and extravagance takes place beyond the boundary of the supply authority's meter, pointing out that the supply authority ought to have some means of checking this in the consumers' interests and the interests of electric lighting in general. It is in towns like Harrogate and Tunbridge Wells, where the electricity works have to depend upon the lighting load for their main revenue, that these facts are brought very severely home to the engineer; and I venture to think that many of those works which have had the good fortune to obtain tramway load to help them over the difficulty would now be in a very serious financial dilemma were it not for the tramway load, if they had to depend upon the lighting load *only* to pay their way. The renewing of blackened lamps, and some means by which the consumer is compelled to renew the lamp when it is worn out, would be a great boon. I find that printing notices on the accounts, and sending out quarterly letters to the consumers, calling attention to the serious waste taking place due to the continual use of lamps that are worn out, have very little effect, and I have for years advocated the necessity for the supply authority inspecting, changing, renewing, and advising on consumers' lamps. Unfortunately, there is no power in the ordinary Electric Lighting Acts to enable this work to be undertaken. I believe if the supply authorities were to adopt the same principle as the gas companies do with incandescent mantles, viz., maintain them at so much per burner per quarter, gas would cease to be so severe a competitor of incandescent electric lighting. I do not agree with the author in his remarks about contractors supplying lamps, and I think the best answer that can be given to this is mentioned by himself, where he states—"If they cannot retain it, their business would no longer be remunerative." That is one of my Mr. Boot.

Mr. Boot. most serious objections; it costs a consumer so much more to renew his lamps because the wiring contractor is not satisfied with a small profit on the lamp; he expects to see 100 per cent. on its net cost to him, and so he does the supply authority grievous injury; whereas if the supply authority made a point of renewing consumers' lamps and maintaining them, as the gas companies do with their mantles, the cost to the consumer of electric lighting as a whole would be greatly reduced. I am aware it would hit a certain number of contractors at first, but, ultimately, it would be largely for their benefit, because electric lighting would become so popular and satisfactory that many more people would have their houses wired. It has not been found that the gas companies' undertaking the maintenance of gas mantles, etc., has done very serious damage to gasfitters and the local ironmongers; even if it were to do harm, it is one of the accepted principles of municipal trading, *i.e.*, "the greatest good to the greatest number," and no reform can be started without injury to some section of the community. It is with satisfaction that I note how successful Mr. Wilkinson has been with regard to the certification of lamps; but I do not understand the figures he gives: I have never come across lamps in my experience taking so many watts per c.p. as he gives. Lamps that blacken prematurely are only too frequently met with. It is becoming more difficult to keep the regulation of pressure within 2 per cent. every day, owing to the demand for power at intermittent times, and I have had to draw up strict regulations with regard to the connection of motors to the mains, and the fluctuations to the pressure caused thereby.

Mr. Taite. Mr. C. D. TAITE (*communicated*): Mr. Wilkinson has first called attention to the fact that, at present, a large amount of waste and extravagance takes place on consumers' premises, thus unduly inflating consumers' accounts. That such is the case is not to be wondered at, seeing that the average consumer has only the very smallest knowledge of electrical matters, and, until recently, there has been very little attempt to educate him on the possible inefficiency of his lamps. As incandescent lamps are all made to practically one pattern, it cannot be expected that a consumer should be on his guard against being supplied with inferior lamps; there is also the danger that if he should ask for a high efficiency lamp he might be supplied with a short life lamp, and, probably, he would rather pay more for current than be worried with frequent renewals. How, then, is the consumer to be protected against the waste which at present undoubtedly exists? Mr. Wilkinson has given the answer, when he states that the supply authority must take steps to protect him; in America this is done by supplying every consumer with new lamps free of charge whenever he requires them, and the standard consumption for new 110-volt lamps is 3·2 watts per candle. In this country it is now too late, even were it desirable, for the undertakers to enter into the lamp business, but if all station engineers were to adopt the method which Mr. Wilkinson himself has found so successful, I think it would be an important step in the right direction; I refer, of course, to the certification of lamps

for watt consumption, and for initial candle-power. I, however, cannot go so far as the author of the paper, when he contends that the supply authority should have the power to compel consumers to use certified lamps; my view is that if the consumer is consistently advised by circular and other ways to use certified lamps, and yet fails to do so, he has only himself to blame if his bills are higher than his neighbour's. The system should be permissive and not compulsory, as it would be most arbitrary and contrary to the interests of the industry for a consumer to be forbidden to make experiments with lamps on his own account; give him every facility for making use of the technical experience of the electrical engineer and his staff, but stop at that. The author has referred to the evils of irregular pressure, and there is no doubt that this question has great influence on the matter of lamp efficiency. The Board of Trade regulations allow us 4 per cent. variation from the declared pressure, but, in some cases, particularly where the supply is an alternating-current one, it is an easy matter to keep well within this limit. The automatic regulators, to which the author has referred, are of great assistance in this direction; what is wanted now is a cheap and reliable regulator applicable to self-excited direct-current generators. The regulator, however, cannot be expected to deal with a purely local disturbance on a large network; in such cases, if the station is a direct-current one, additional copper is usually the only remedy; that is a matter which must be settled entirely by local conditions. The author has referred to the action which the Incorporated Municipal Electrical Association are taking with regard to lamp standardisation; I think that when the recommendations of this body in conjunction with the specification of the Standards Committee are issued, they will be found to be acceptable both to lamp-makers and retailers alike, and there is no doubt in my mind but that they will be the means of substantially reducing the existing waste with immediate advantage to the consumer and to the eventual gain of the supply authority. Mr. Taite.

Mr. G. WILKINSON (*in reply*): Mr. Campion, and other speakers following him, referred to the examples of wasteful lamps given in my paper, and intimated that I have quoted exceptional cases; I thought so myself at one time, but I do not think so now, because I have come across numbers of equally bad cases of more recent date which could have been quoted, and fresh discoveries of a like character are constantly being made. When I cited the examples of wasteful lighting given in my paper to my friends on the Council of the Municipal Electrical Association, they expressed the same view that has been expressed here to-night, but after they had looked into the matter in their own towns, they were fully in accord with what I had stated, and some of them produced even worse examples than I quoted. One example has been particularly referred to, viz., the public building in which I found eighty 32-c.p. 100-volt lamps taking an average of 170 watts each. Mr. Dickinson asked if that was not extraordinary. Unfortunately it is not so, as other installations in the town were found with similar lamps. They were Mr. Wilkinson.

Mr. Wilkinson.

British lamps, made by one of the best known firms, and they were returned. I took the trouble to get the figures with regard to the saving in this instance, and I find it amounts to £108 during the last twelve months. I think you will admit that that is a very substantial saving. I took these figures from the ledger before I came away, and, as far as I know, the hours of working and the conditions of usage are identically the same as obtained the previous year; at any rate, if there is any difference it is not much. Respecting the recommendation of separate mains for lighting and power supply, I am afraid that my paper does not clearly explain exactly what I mean. If you have motors and lighting, the lighting wants the first consideration, because it is the backbone of the business. If you can take your motors on the mains without prejudicing your lighting, then do so by all means, but if the motors are so erratic that the voltage varies and destroys the regulation, I say, unhesitatingly, give the lighting the first place, and take some means to put the motors on circuits, so that they will not prejudicially affect the lighting load. I have a very interesting chart, which came from one of my former assistants who is now in South Africa. His station carries a load of about 400 k.w. He found some trouble with the motors on the mains, one, in particular, about a mile and a half away, driving a large circular saw, and on certain occasions it was taking 50 amperes on each phase, and absolutely dislocating his lighting load (3-phase network). I told him to get an automatic regulator. He has done so, and the pressure chart produced is the result. The motor coming on or going off causes a momentary kick on the chart, but the regulator otherwise gives him a steady pressure and fair lighting, whilst he still retains his motor. It could not be done by hand regulation. Mr. Blackman gave us a very interesting explanation of his chart, which, of the direct-current charts, is the best shown. I must congratulate him on his switchboard attendants. Mr. Campion asks what life can be obtained from a 220-volt lamp, and what sort of regulation is necessary. It is quite within reasonable practice to get within 2 per cent. of standard voltage, under which condition lamps have a satisfactory life. I cannot give any information furnished by the lamp-makers to the Physical Standards Sub-Committee, as it is of a private character, but it will doubtless be published in due time. I may say, however, that the pressure regulation asked for in their proposed specification is such that a supply station engineer cannot obtain under existing working conditions. As long as we have lamps with carbon filaments we must keep our regulation within 2 per cent. The Municipal Electrical Association have prepared a specification for carbon filament lamps, but, at the request of the Standards Committee, it is withheld, but it is important that they should hurry up and get something done for the industry before the ordinary pear-shaped clear glass lamp is out of date. If we are not prompt, we shall get the specification after we have got a better lamp, when it will be of little value. Mr. Blackman thinks my scheme a cumbersome arrangement. I do not

think so, and I quite agree with Mr. Emmott that the contractors are worthy of more consideration than Mr. Blackman allows. Because he alleges they do scandalous work he would render them less able to do good work by taking the lamp business away from them. I would help the contractors all I could, because they help us a very great deal. If, as Mr. Blackman says, they do bad work now, they will probably do worse work when they are without the profits from the continuous sale of the lamps. I do not agree with municipal authorities taking hold of every branch of business and carrying it on in competition with ratepayers in their districts. I do not think they have any right to encroach on private trade in this way. It is very clear, from Mr. Blackman's admissions, that the Bradford Corporation have got into hot water through supplying inefficient foreign lamps. My paper shows the British-made lamps are sometimes inefficient, and, if such lamps are supplied free of charge, the consumer's bill goes up and he goes over to the use of gas. It does not take much nowadays to frighten them into the arms of a gas company. I think it would be wise to check very carefully the British-made lamps, even when they are supplied free, as at Bradford, because they require it. I was very glad to hear one or two speakers, including Mr. Wilson, invite the engineers to co-operate and seek information from the lamp-makers. A very good purpose would be served by doing this, and thus getting the information which is in the hands of the manufacturers. So far as my experience goes, they have always been willing and ready to give information and any advice that has been asked. I can recommend my colleagues to go to this source for information, and I feel sure that they will not be disappointed. Mr. Dickinson referred to the unsatisfactory experience he has had in Leeds with the Nernst lamps. The Nernst lamp is not perfect; there are many points that ought to, and could, be very easily altered, but the Germans have such a demand for these lamps that they will not listen to the English requirements. In six out of seven failures in street lamps, I find extinction is due to nothing else but the contacts on the lamp getting out of line with the contacts in the lamp-holder. If they were to make wide contacts on the Nernst lamps, such as those which an ordinary incandescent lamp has, they would get much better results. I made a test of 90 Nernst lamps, taking a careful note of each one, and I obtained an average life of 520 hours; they were fixed in street lamps and subject to vibration. I believe the long average life is attributable to the good pressure regulation we have. I regret the discussion has not brought out more information about Nernst lamps. With reference to the alteration of Clause 18 of the Electric Lighting Act, I do not think we can have satisfaction without this alteration, so as to give a measure of control to the supply authority. As far as water companies are concerned, I should like to say that they have a statutory right to examine and put a stamp on every tap and every valve that is put on the supply system. We want the right to see that the lamps used on our mains are

Mr. Wilkinson.

Mr. Wilkinson.

such as will give the consumer a fair return for what he pays. We cannot tell from the tests recommended in my paper whether the lamp is in for a long life, but we advise the merchants to get a guarantee from the lamp-makers that the lamps shall last a certain number of hours, and, as we give the consumers information on this point by our printed notices, they have a fair idea as to how long the lamps should last.

MANCHESTER LOCAL SECTION.

"IDLE CURRENTS."

By M. B. FIELD, Member.

(*Paper read February* 13, 1906.)

"Through Idleness . . . . . . the House leaketh."

EXPLANATION OF SYMBOLS AND EXPRESSIONS.

C C_1 C_2 etc.	= current in amperes.
R r	= resistance in ohms of circuit or conductor.
f	= frequency, cycles per second.
B	= induction density, lines per sq. cm.
l	= thickness in cms. of conductor strip (Disc type armature).
ρ	= specific resistance in ohm-cms.
a	= width of slot, in cms.
d	= ,, in cms. of conductor in slot.
b	= depth in cms. of ,, radially.
Δ_0	= amplitude of nominal current density, amperes per sq. cm. in conductor.
Δ	= instantaneous value of actual current density.
x	= distance in cms. measured radially from root of conductor.
V	= E.M.F. in volts per cm. length of conductor at x generated by cross flux; or the E.M.F. generated by the cross flux in a certain rectangular circuit defined on page 97.
N	= total flux surrounding imaginary lamina at x, or the total flux threading the above imaginary circuit.
	= distance in cms. between two imaginary planes cutting conductor normally.
v	= difference of potential in volts between these planes.
l_1	= length of slot plus allowance for fringes.
m	$= \sqrt{\frac{2\pi p}{10^9 \rho} \cdot \frac{l_1}{l} \cdot \frac{d}{a}}$ – Dimensions $L^{-1}T^0M^0$.
p	$= 2\pi f$.
n	$(n-1)$ is number of conductors below the one under consideration, counting the conductor nearest slot root as 1, the next as 2, and so on.
δ_1 δ_2	= quantities of the same dimensions as current, appearing in the developed expression for Δ.
β_1 β_2	= constants of integration.

K_n	= coefficient of increase of resistance of n^{th} conductor.
q	= ratio of active length of conductor to length of half turn.
P	$= \frac{\rho}{d}C^2$; $\frac{P}{b}$ = nominal C^2R loss per cm. length.
λ	= distance in cms. from middle of armature, measured longitudinally along slot.
T	= Temperature of armature conductor in degree Cent.
T_1	= " " " in centre of armature.
T_0	= " " " at end of "
D	= R.M.S. value of nominal current density, amperes per sq. cm.
${}_iK_n$	= K value for n^{th} conductor, corresponding to a frequency i times that of the fundamental.

APPENDIX :—

xy	= rectangular co-ordinates.
V	= difference of potential in volts of conductor measured between two normal planes 1 cm. apart.
$\phi(xy)$	= function expressing the specific resistance in ohm-cms. at point xy.
$f(xy)$	= function expressing actual current density in amperes per sq. cm. at point xy.

Idle-Current. This expression, as employed in this paper, includes all currents which do not perform any useful work, and consume energy to the extent of their C^2R loss. It thus includes eddy currents.

Natural distribution of Current Density. The distribution that would obtain if the current were continuous and no disturbing influences brought to bear, *e.g.*, self-induced E.M.F.'s and E.M.F.'s induced by external agencies, thermo-electric effects, etc.

Lamellar effect. Where the current density is a function of x only, and may be considered as flowing in layers along the conductor ; the current in adjacent layers may have different phase relations.

Nominal Current Density and C^2R *loss.* The current density and C^2R loss calculated on the assumption of a natural distribution as above defined.

Loss Density. The actual C^2R loss per cub. cm. at any point. In conductors where the current density varies from point to point, the loss per cub. cm. must likewise vary.

Coefficient of increase of resistance. This is equal to the ratio of the actual to the nominal C^2R loss.

Critical Depth. That depth of solid armature conductor, at which, other things being fixed, the actual C^2R loss is a minimum.

Temperature Gradient. The rate of change of temperature in degrees Cent. with distance in cms. measured longitudinally along conductor.

SYNOPSIS.—Introductory—Scope of paper—Characteristic of Idle Current —Power Factor—I.C. due to inductance, remedy—Practical illustration—I.C. due to capacity, example, remedy—Irregular wave shape may involve I.C.— Cross-currents—Internal I.C. in dynamo-machines—Sub-division into two broad classes—Uniform distribution of current density equivalent to uniform distribution plus I.C.—General theorem, Appendix—Numerical example—

Diagrammatic representation of various forms of I.C. in group of machines in parallel. Decrease of copper in armature may result in increased efficiency —Illustration, disc type armature—Ottenstein's experiments—Stray field magnet flux in armature slots—I.C. losses thereby produced—" Lamellar effect "—A. B. Field's paper—Approximate numerical calculation of lamellar effect—Curves of current density distribution, and loss density in conductor in slot, Fig. 8—Analytical investigation—Coefficient of increase of resistance due to lamellar effect—Graphical representation, expression for ditto—Curves of coefficient of increase of resistance, Fig. 9—Examples, illustrating use of curves—Critical depth of conductor of armature—Curves 10, 11, critical depth of multiple layer winding—Increase of specific resistance of armature conductor may improve efficiency—Windings with graded cross-sections, numerical examples—Application of results to Niagara alternators—Possible economies—North Metropolitan Company's alternators—Other considerations bearing on conductor dimensions—Temperature gradient—Calculation of ditto—Critical depth for ditto—Mechanical forces on end connections—Illustrations—Inductance of winding—Lamellar effect in D.C. machines—Calculation of ditto—Comparison with alternators—Rotary Converters—Effect of tooth saturation—Closed slots.

It has ever been a trite saying among laymen that electricity, unlike other saleable commodities, cannot be adulterated. Nevertheless, the engineer knows too well how very inapt such a statement is. He knows, for example, that the product of amperes and volts, as indicated on his alternate current switchboard, is no measure of the power at his disposal, but that he must multiply by a reducing coefficient, which he terms the "power factor," in order to arrive at the available watts. He knows that his useful or working current is, as it were, *adulterated* with a useless idle current, for which he can obtain no manner of remuneration (except in some rare instances); while he is not forgetful of the fact that the same useless commodity must be paid for by him with coal, oil and water, not to mention a proportion of the prime cost and yearly depreciation of his plant.

So, indeed, it is with all the varieties of idle current peculiar to electric systems; we find them ever cropping up in different forms in direct, as well as in alternate current installations, until we almost dread them as diseases sapping the vitality of the system.

Nor, indeed, are they confined to the current-carrying conductors themselves, but with every appearance of contagion are generated and reproduced in almost any available metallic mass in the neighbourhood; for example, we find them in the pole-pieces of dynamos, the cores of transformers, in the sheathing of cables, the cases of measuring instruments, and so on.

In the following paper we shall restrict ourselves to a short general discussion of the idle currents met with in the main conducting circuits, and then examine, with somewhat greater detail, one particular effect, which probably deserves more consideration on the part of designers, than has been accorded it heretofore.

The characteristic of every form of idle current here dealt with is that, while constituting a part of the *total* current flowing in the circuit,

it may be considered, conventionally, as an altogether separate entity superposed upon the real useful current, and be treated as such.*

To illustrate this, let us take the case of an alternate-current system where the power factor is less than unity.

Let C_1 be the amplitude of the useful or power component, C_2 that of the idle component of the current. The main ammeter indicates as we know,

$$\sqrt{(C_1^2 + C_2^2)/2}.$$

If this current flow in a conductor of resistance r ohms, the time-average value of the ohmic loss will be

$$(C_1^2 + C_2^2)\frac{r}{2}.$$

Considering the power and idle components as separate entities, we obtain for the ohmic losses due to each,

$$\frac{C_1^2 r}{2} \text{ and } \frac{C_2^2 r}{2}$$

respectively, so that the sum of these losses is identical with the time average loss due to the actual total current flowing.

It will be scarcely necessary to point out that this is not generally true of any arbitrary sub-division of a current into component parts, *e.g.*, a current of 10 amperes flowing through a conductor of 1 ohm resistance would represent an ohmic loss of 100 watts. Magnetically, this current would be equivalent to one of 15 amperes flowing in the positive direction superposed upon one of 5 amperes flowing in the negative direction. The sum total of the ohmic losses of these components would, however, be $225 + 25 = 250$ watts. While, therefore, it is self-evident that a current may not be resolved into any arbitrary components, and these be treated from all points of view as separate entities, yet we may always treat the power, and idle current components as if they existed independently of each other.†

This very simple conception is of material assistance in the consideration of some problems; for example, a certain distribution of current in a system of conductors may be a very complex matter to deal with as a whole. If, however, we can show that the complex distribution is equivalent to a "natural" distribution superposed upon an idle current, and we can isolate the cause of the idle current, we may be able to estimate its value, and hence arrive at the characteristics of the actual complex distribution.

* We must make one reservation here; when dealing with the C^2R losses, in certain cases only, is the ohmic loss due to the total current flowing, equal, *at every instant*, to the sum of the ohmic losses of the two components, but, in every case, this is true of the time-average values.

† As regards those effects which are determined by a linear function of the current, as for example the magnetic induction in a medium of constant permeability, the current may be divided into any abitrary components whose algebraic sum equals the value of the total current flowing. For those effects which depend upon a quadratic function of current we may consider the power and idle components as currents existing independently of each other. For effects represented by a more complicated function such as saturation effects, even this sub-division is no longer permissible.

Power Factor.—The idle current present when the power factor is not unity, frequently circulates throughout the entire circuit, and in such cases generators, mains, transformers, and other gear must be constructed with ampler proportions accordingly. The two main causes of the defective power factor are :—(*a*) Inductance in the load, as, for instance, when induction motors are largely employed ; (*b*) Capacity in the overhead lines or cables.

The only effective remedy in the first case, where the matter reaches serious proportions, is to run over-excited synchronous motors at the load end of the line. These may be considered either as motors *absorbing* a leading current, or as generators running in parallel with the station and *supplying* the necessary lagging current at the far end of the line, thus relieving the generating station of the necessity of doing so, and the line of the necessity of transmitting anything but the power component or working current.

The calculation of the capacity of synchronous motors for the above purpose, in any specific case, is a matter of great simplicity, and need not concern us here. As an interesting analogous example, however, the following details may be mentioned ; the case having come within our personal experience.

In a certain water-driven station six generators, each coupled to a 300 H.P. turbine, were first installed. The generators, which we will designate by the letter A, were found to have an excessive reactive drop, so that, under average conditions (power factor between ·7 and ·8) the maximum load obtainable from the generators without lowering the normal busbar E.M.F. corresponded to only two-thirds the full output of the turbines. The expedient that was adopted to overcome the difficulty was the following : When the station load had increased to the available limit of the 6 A generators, extension generators—B —were designed, capable of considerable over-excitation. These, although *electrically* much larger than 300 H.P., were coupled to turbines of the same size as those driving the A generators, but, when running in parallel with the latter, the B generators supplied the whole idle current required by the station load, entirely relieving the A generators from the necessity of supplying anything but power current.

The result was that the generators first installed were enabled to take up the full H.P. of the turbines to which they were coupled and still maintain the normal terminal E.M.F. It was found, as indeed was to be expected, that if the B generators were paralleled, and the water supply cut off, so that they were running merely as unloaded synchronous motors, the load on the A generators could be increased 50 per cent., notwithstanding a material reduction in their excitation, the busbar voltage being maintained by a suitable manipulation of the field regulators of the unloaded generators.

The second instance enumerated above of defective power factor due to line capacity, only assumes serious proportions in the case of very long transmission lines at very high voltages.

Suppose, for example, we consider a 3-phase transmission line,

100 miles long, working at 80,000 volts, 25 cycles, the lines being OOB and S arranged Δ-fashion 36 in. apart, and at an average of 30 ft. above the ground. It is a simple problem in electrostatics to calculate the current flowing into the line due to capacity effects. It works out approximately 18 amperes per phase, or about 2,500 apparent k.w. It will at once be seen that such an enormous apparent load for each set of three line wires would be a most serious item for the generating station to deal with.

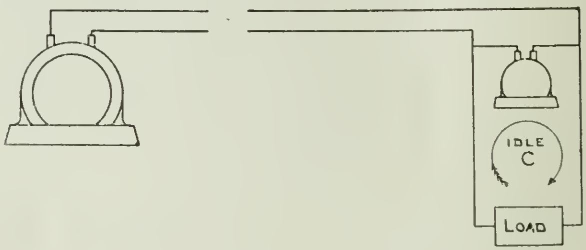


Fig. 1.

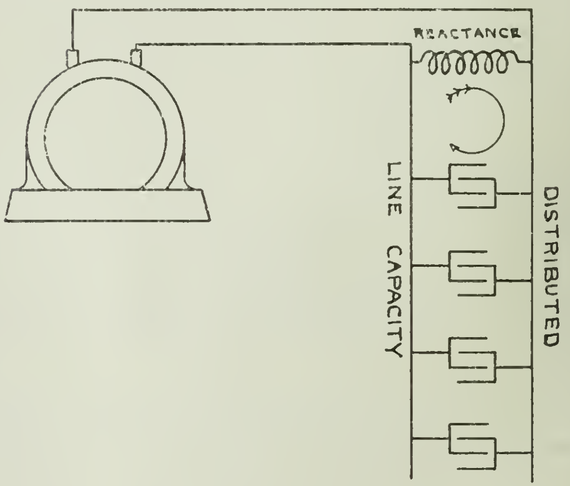


Fig. 2.

Messrs. The General Electric Company, of Schenectady, have manufactured reactances for voltages as high as 60,000 and for 2,500 apparent k.w., for the purpose of relieving the generating station of the relatively enormous idle currents which are met with in such cases.

It will, however, be observed that the use of synchronous motors and reactances does not cure the evil, but only mitigates it In the first case the line and generators are relieved of the idle current, if the

synchronous motors be situated at the far end, *i.e.*, the idle current is restricted to the environs of the load, circulating between the over-excited synchronous motors and the induction or other motors which constitute the load.

In the second case the generating machinery is relieved of the idle current by the use of reactances, but the idle current is not entirely eliminated, for it still circulates in the localised circuit formed by the reactance and capacity shunts.

The two cases are diagrammatically shown in Figs. 1 and 2, and it is easy to see that the total C^2R loss is equal to the sum of the C^2R losses of the working current in the whole circuit, and of the idle current in the local circuit.

Wave Shape.—Irregularity of wave shape may introduce idle currents, although this is by no means necessarily the case. Let us suppose that the E.M.F. of a supply circuit is not a pure sine law, and consider a motor connected thereto whose back E.M.F. varies as the sine law. Evidently the current supplied to the motor will have harmonics in its constitution. Let the fundamental amplitude be C_1 and the amplitudes of the succeeding harmonics C_2, C_3, etc., then C_1 will alone be the working current, while both C_2 and C_3, etc., constitute idle currents, and as such are, of course, undesirable. On the other hand, if the same supply E.M.F. be applied to a bank of lamps the current flowing will likewise contain harmonics. In this case, however, we cannot consider them as idle currents, for they produce heat, and therefore are as beneficial from the lighting and heating point of view as is the fundamental.

Cross Currents.—The currents circulating locally between the various units of a group of alternators running in parallel, may again represent an instance of idle currents. But, as in the last example, the cross-currents (though at all times undesirable) are not invariably idle, as they may represent a pulsating transference of power from one generator to another, and *vice-versâ*. This is the phenomenon of hunting or surging. Fig. 3 represents an idle current circulating between two alternators in parallel.

Internal Idle Currents.—Passing over the various classes of idle current to be looked for in the external circuit, we will now turn our attention more particularly to those which are manifested inside the alternator, motor, or transformer, as the case may be.

The internal idle currents may be classified broadly under two heads: (*a*) Those whose magnitude is determined by the degree of excitation, and which depend very slightly, if at all, upon the load; (*b*) those whose magnitude is determined by the load and which depend very slightly, if at all, upon the excitation of the machine. Both produce a disturbance of the natural current density in the conductors of the machine, and increase the losses in consequence. The first class may be said to add a definite constant loss (for a given excitation) to whatever loss would be occasioned by the natural distribution of current density, while the second produce an additional loss proportional to the square of the working current, hence the actual loss

may, in this case, be determined by simply assuming a *virtual increase of the resistance* of the circuit. The exact meaning of this will be better appreciated later, but as an example we may mention that the so-called skin-effect in a solid conductor traversed by an alternating current is really due to an idle current proportional to the working current flowing, while the total loss due to idle and working currents may be determined by simply assuming the resistance of the conductor has been, by some means, increased. Again, the additional loss in the sheathing and cores of a cable are proportional to the working current, and the total loss may be estimated by assuming an increase of the resistance of the conductors. The coefficient by which the actual resistance must be multiplied to allow for the additional losses depends upon the frequency, specific resistance, and dimensions of the conductor.

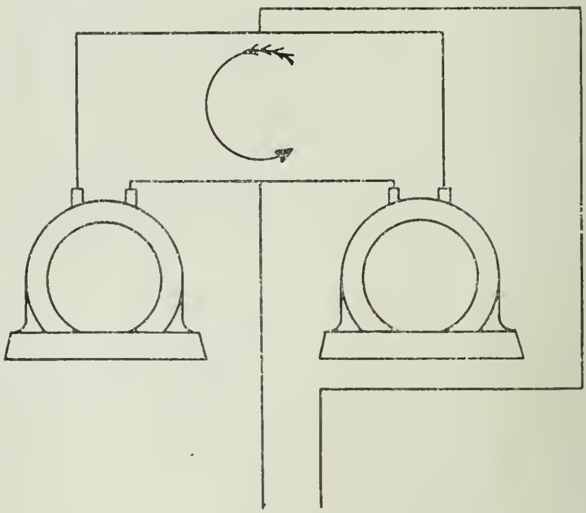


FIG. 3.

Large generators usually have two or more paths through the armature, and an uneven distribution of current between the various paths, is equivalent to a uniform (or natural) distribution superposed upon a system of idle currents. Again, each path may be composed of two or more conductors, laminæ or strands in parallel, and an uneven distribution between them is equivalent to a natural distribution plus an idle current. Lastly, the distribution of current density in each individual strand may be far from uniform, so that here again we have an idle current superposed upon a natural distribution.

In the appendix to this paper will be found a general theorem proving the truth of these statements. The theorem shows that, if current be flowing in any system of conductors connected in

parallel, whatever the current distribution may be, it is always identical (as regards linear and quadratic functions) with a "natural" distribution, superimposed upon a system of idle currents. By a "natural" distribution we imply the distribution that would obtain if the current were continuous, and no disturbing influences brought to bear.

The following very simple calculation is given for the benefit of those who dislike generalities, but prefer to confine themselves to concrete examples. We wish to show that if current flow in Fig. 5 (*a*) *viâ* the loop, as indicated by the arrow heads, but does not divide uniformly between the two branches of the loop, the total ohmic loss in the loop will be that due to the natural subdivision of current, plus the loss due to a current circulating within the loop, in fact, the un-uniform distribution is identical with a uniform distribution superimposed upon an idle current. $a\ b$, $a^1\ b^1$, Fig. 5A, are two current paths each of resistance r ohms, and the currents $C_1\ C_2$ flow in the direction indicated by the arrows. The total ohmic losses are given by the expression

$$C_1^2\, r + C_2^2\, r,$$

but we observe that

$$C_1^2\, r + C_2^2\, r = 2\left(\frac{C_1 + C_2}{2}\right)^2 r + 2\left(\frac{C_1 - C_2}{2}\right)^2 r.$$

The first term or the right-hand side is the ohmic loss due to the natural distribution of current, *i.e.*, an equal subdivision between the two paths of the total current $(C_1 + C_2)$ flowing, while the second term represents the ohmic loss due to an idle current of value $(C_1 - C_2)/2$ flowing in the loop $ab\ b^1\ a^1$. Thus (A) and (B), Fig. 5, are in all respects identical.

Fig. 4 shows pictorially the various idle currents above referred to as existing in a single complex circuit; when we consider that we have so far only dealt with the main current-carrying circuits themselves, and allow ourselves to reflect upon the multiplicity of idle currents induced in neighbouring metallic bodies (core plates, pole-faces, etc.), we gain some idea of the many ramifications of the whole subject of "Idle Currents." The remedies, or partial remedies for idle currents of one form and another, as they exist in dynamo machines, are fairly well appreciated, *e.g.*, equalising rings connected to the windings of large continuous-current dynamos, the use of stranded and laminated conductors, etc., etc. It sometimes occurs, however, that one particular class of idle current may predominate to a totally unexpected extent, and in fact a cooler, cheaper and more efficient machine may be obtained by a decrease of the amount of copper therein. As an illustration, the following may be cited, though the reference is to a type of machine which is now practically obsolete, viz., the ironless flat disc alternator.

In Fig. 6 two poles of such a machine are represented with a portion of the armature consisting of copper strip wound into flat coils. Each strip as it passes edgewise through the magnetic field has an idle

current induced into it. To calculate the loss we may apply the eddy-current formula used for iron armature plates and the like,* viz. :—

Loss in watts per cub. cm.

$$= \frac{f^2 B^2 t^2}{6 \times 10^{15} \rho};$$

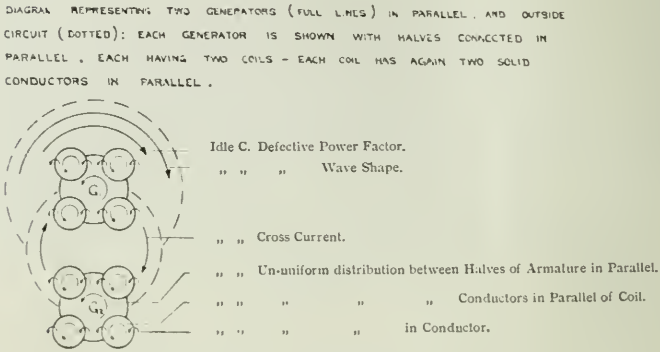


FIG. 4.

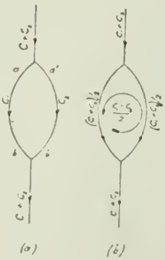


FIG. 5.

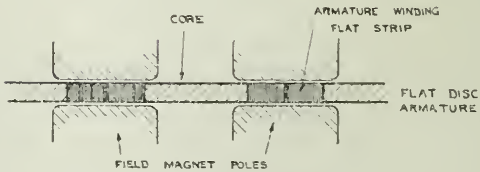


FIG. 6.

* This formula is applicable so long as the lines of force pass straight across the gap from pole to pole, the variation of induction being assumed to follow a sine law, and provided the thickness of the strip does not permit of idle currents of such magnitude as to sensibly disturb the distribution of magnetic lines, a contingency not likely to arise in the case under consideration.

where t = thickness in cms.

f = frequency, cycles per second.

B = induction density in air-gap lines, per sq. cm.

ρ = specific resistance in ohm-cms.

Let us take the nominal maximum current density at 310 amperes per sq. cm. (= 2,000 amperes per square inch), then the nominal C^2R loss will be 0·18 watts per cub. cm. at about 45° C.

Applying the formula above, for the loss due to idle currents, we have for

$$f = 50,\ B = 5{,}000,\ \rho = 1{\cdot}9 \times 10^{-6}.$$

t = 0·1 cm. loss per cub. cm. = 0·0548
t = 0·2 „ „ „ = 0·22
t = 0·3 „ „ „ = 0·493

and so on, hence, with an armature wound with strip 2-mm. thick the additional loss due to disturbance of current density in the active part of the armature conductors is greater than the nominal C^2R loss. It is to be feared that this state of affairs exists in a considerable number of machines in use at the present time. The result of using thinner strip might be to reduce the heating, and might increase the efficiency and provide a lighter and cheaper machine. For the same reason it is clear an increase of the specific resistance would cause a decrease of the total losses, hence we have the somewhat paradoxical condition that the efficiency improves as the temperature increases.

Our attention has been called to an interesting investigation published in Germany in 1903 by Dr. Simon Ottenstein, giving the results of tests made to determine, among other things, the "eddy-current loss" in solid copper conductors laid in slots, due to the radial and tangential components of the flux within the slot, *which emanates from the field magnets*, this flux being quite independent of the load current in the armature conductors. The title of the investigation is "Das Nutenfeld in Zahnarmaturen und die Wirbelstromverluste in Massiven Armatur-Kupferleitern." The armatures experimented upon had a diameter of 225 mm., and the slots were dimensioned in the different armatures as follows: 7 × 22·5, 7 × 35, 9 × 35·5, 7 × 23, 8·5 × 23, 14 × 11·75, the first dimension giving slot width and the second the depth in mm.

In the different experiments the theoretical tooth induction varied from 18,000 to 31,000, and the eddy-current losses in the various solid conductors employed were found to be equivalent to the loss that would have been occasioned by a current density of from 400 to 4,700 amperes per square inch in the active portion, depending upon size and position of conductor, dimensions of slot, air-gap, and nature of polar surface. The frequency in all these experiments was 33·3.

We have dwelt at some length upon this point on account of what follows; we shall see that an analogous case exists in other historical machines due to an effect to which we shall confine ourselves in the remainder of this paper. We refer to the ununiform distribution of an

alternating current over the cross section of a rectangular conductor surrounded on three sides by iron laminations.*

The two previous examples cited are cases where the magnitude of the losses are dependent upon the degree of excitation and not upon the load on the machine; the following, however, represent the other case, where the losses are dependent upon the load current and not upon the degree of excitation.

In Fig. 7 we have represented a copper conductor of depth *b* cms. and thickness *d* cms. lying in a slot of a laminated armature. An alternating current flows in the conductor in a direction at right angles to the plane of the paper, the plane of lamination of the armature

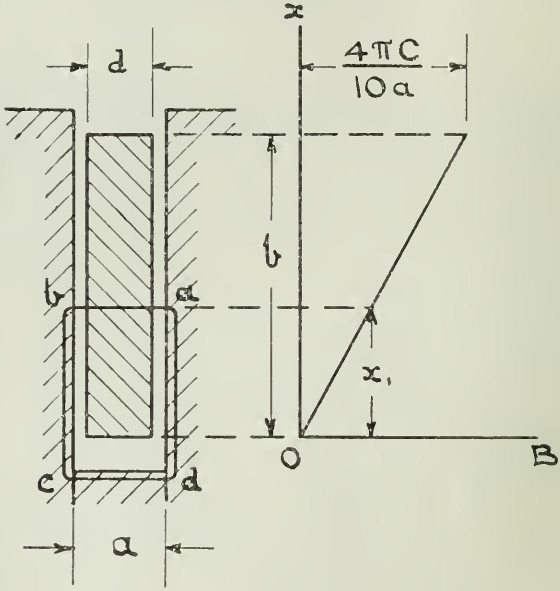


Fig. 7.

plates corresponding with that of the paper. We shall show that the current flows in layers, being densest in the outside layers at the mouth of the slot, and least dense at the root. For this reason we have thought that the term "lamellar effect" is not out of place in describing this phenomenon. It is, of course, closely allied to the skin effect

* For the first portion of what now follows the writer is indebted to notes and calculations on the subject sent him by his brother, Mr. A. B. Field, in U.S.A. After the greater portion of this communication was drafted, Mr. A. B. Field submitted a paper entitled "Eddy currents in Slot-wound Conductors," to the American Institute of Electrical Engineers, which held its meetings at Ashville, U.S.A., last year, and the paper is to be found in the transactions of the American Institute of Electrical Engineers. In view of the importance of the subject, and also because the Proceedings of the American Society are not widely perused by British engineers, the writer has ventured to reproduce some of the figures and curves in the paper referred to, and to somewhat further develop their applications to practical problems.

in a circular conductor, where the idle currents flow in one direction along the peripheral portions, and in the opposite direction along central portions.

The effect of any current flowing down the conductor in Fig. 7 will be to produce a magnetising flux across the slot from side to side. If the width of the slot be small compared with the depth the lines will be very nearly straight from wall to wall, except near the mouth of the slot, where they will bow outwards.

If *a, b, c, d* be a line of force, we know that the total magnetic force (or line integral) taken round the closed path will be $\frac{4\pi}{10}$ times the total current in amperes in that portion of the conductor enclosed within it. Now, the magnetic resistance of the iron portion of the path, *i.e.*, from *a* to *d* to *c* to *b* is negligible in comparison with the air-portion from *b* to *a*, hence we may say with great accuracy that the line integral of magnetic force from *b* to *a* equals $\frac{4\pi}{10}$ times the current in amperes flowing in the conductor between the limits $x = 0$ and $x = x_1$. The induction density at the mouth of the slot is therefore $\frac{4\pi}{10}\frac{C}{a}$, where C is the total current flowing in the conductor ; and the induction at the slot root is zero. If, now, we suppose that the density of the cross-induction increases uniformly from zero value at the root of the conductor to $\frac{4\pi}{10}\frac{C}{a}$ at the top edge, the total flux traversing the conductor will be—

$$\frac{4\pi}{10}\frac{C}{a}\cdot\frac{b}{2}$$

per cm. length.

Consider a very thin lamina along the top edge of the conductor forming, in conjunction with a similar lamina along the lower edge, a loop through which this total flux threads.

The E.M.F. induced in this loop per cm. length of conductor will be—

$$\frac{4\pi^2}{10}\frac{bfC}{a}10^{-8}$$

volts where f is the frequency of alternation. This expression gives the R.M.S. value of volts if C represents the R.M.S. value of the current. If the conductor be long in comparison with its cross section, such an E.M.F. would produce an idle current flowing in the loop of value of which the current density is—

$$\frac{2\pi^2}{10}\cdot\frac{bfC}{a\rho}10^{-8}$$

where ρ is the specific resistance in ohms-cms.

As an example we will write $f = 50$, $b = 5$ cms., $\frac{d}{a} = 0{\cdot}7$, $\rho = 1{\cdot}9 \times 10^{-6}$ (at about 45° C.) when the value of the idle current density

works out at about $2{\cdot}6\,\frac{C}{a}$; but the nominal current density is $\frac{C}{5\,d}$; hence the idle current density in the outer layers is over nine times the nominal current density when worked out on this basis, and the loss density (or loss per cub. cm.) at the extreme edge due to the idle current is over 80 times that due to the nominal current density.

This example has been cited to show in a rough-and-ready way that some phenomenon occurs in such conductors, which is well worth while studying. The assumption made that the distribution of cross flux is that which would be given by a uniform current density is obviously disproved by the result of the calculation, and the actual redistribution of the cross flux is such as to materially reduce the estimated idle current effect. While, therefore, the above result is

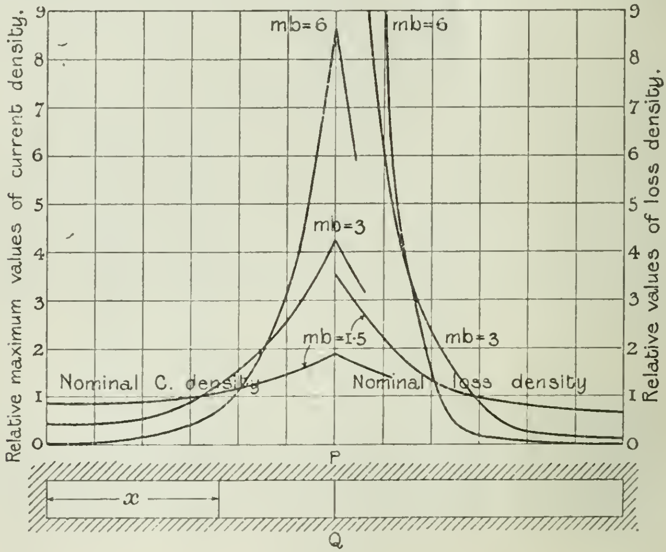


FIG. 8.

Taking $\frac{d}{a} = 0{\cdot}61$ and $f = 50$, the value of m is $0{\cdot}8$, hence

$mb = 6$ corresponds to $b = 7{\cdot}5$ cms.
$mb = 3$,, $b = 3{\cdot}75$,,
$mb = 1{\cdot}5$,, $b = 1{\cdot}875$,,

greatly exaggerated on account of the assumption made, it may be mentioned that machines are at work to-day where the loss density in the outer edge of the conductor is as much as thirty times that due to the nominal current density.

Fig. 8 represents the case of two conductors lying in a closed slot, current flowing up one and down the other.

The effect in each conductor will be the same as if we had but one conductor lying in an open slot, of which the mouth was at P Q,

except for the fact that the tendency of the lines to bow outwards at the mouth will here be largely neutralised. Curves in Fig. 8 show the distribution of current and loss* density in the conductors, it being assumed that $f = 50$; $\frac{d}{a} = 0{\cdot}61$, and b has the values $1{\cdot}875$, $3{\cdot}75$, and $7{\cdot}5$ cms. We will now proceed to show, as briefly as possible, how such calculations are made.

Let $\Delta_0 \sin p\,t$ be the nominal current density in each conductor, so that $b\,d\,\Delta_0 \sin p\,t$ represents the total current flowing in the conductor.

Let us confine our attention to the left-hand conductor in Fig. 8, and consider x as distance measured from the root of the conductor towards the centre of the slot. Within the length of the slot the current density will be disturbed, hence let Δ be the actual instantaneous value at x.

Let ρ = specific resistance in ohm-cms.

Let V = E.M.F. in volts per cm. length generated at x by the cross flux, or perhaps, more strictly speaking, the E.M.F. in volts generated by the flux threading an imaginary rectangular circuit, whose plane is parallel with the walls of the slot. The circuit is composed of two sides each 1 cm. long, passing longitudinally through x, and at right angles to P Q respectively, the remaining sides being in the plane of lamination (Fig. 8A).

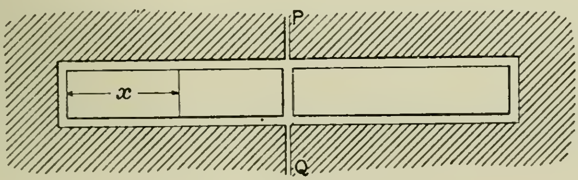


FIG. 8A.

Where the conductor emerges from the slot, the current will redistribute itself and become uniform, and the potential at all points of the conductor in any plane parallel with the plane of lamination (of iron) will be the same.

Consider two such planes, one at each end of the iron armature, but just far enough outside for the current to have become uniform, and let the distance between them be l cms.; and the potential difference be v. Remembering that the flow of current in the conductor within the slot is lamellar, Ohm's law for the current at x will be—

$$v + V\,l_1 = \Delta\,\rho\,l,$$

l_1 being the length of the slot plus an allowance for fringes at the ends.

V and Δ are functions of x, but v is independent thereof, hence differentiating we have—

$$\frac{d\,V}{d\,x} = \frac{l}{l_1}\,\rho\,\frac{d\,\Delta}{d\,x} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

* The loss density at a point is the loss per cub. cm. at that point.

If C be the total current in the conductor between the limits $x=0$, $x=x$, the induction density at x will be $\frac{4\pi}{10}\frac{C}{a}$. The total current in the conductor between the limits $x=0$ and $x=x+\delta x$ is $C+d.\Delta\,\delta x$, and the induction density at $x+\delta x$ will be—

$$\frac{4\pi}{10}\left(\frac{C+d.\Delta\,\delta x}{a}\right)$$

d being the thickness of the conductor, hence

$$\frac{dB}{dx}=\frac{4\pi}{10}\cdot\frac{d}{a}\Delta \quad \ldots\ldots\ldots\ldots \quad (2)$$

V being the E.M.F. induced at x per cm. length by the cross flux, is equal to

$$-\frac{dN}{dt}10^{-8}$$

where N is the total number of lines which may be considered as surrounding the imaginary lamina at x or as threading the imaginary rectangular circuit as above defined; but

$$-\frac{dN}{dx}=B.$$

Hence

$$\frac{dV}{dx}=10^{-8}\frac{dB}{dt} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Equations (1), (2) and (3) are the fundamental equations of the problem; we can now eliminate V and B and obtain

$$\frac{d^2\Delta}{dx^2}=\frac{4\pi}{10}\frac{d}{a}\cdot\frac{l_1}{l}\cdot\frac{1}{\rho}\cdot 10^{-8}\frac{d\Delta}{dt} \quad \ldots\ldots \quad (4)$$

which is the differential equation defining the current distribution in the conductor. The solution of this equation is—

$$\Delta=\delta_1\,\epsilon^{mx}\sin\left(pt+mx+\beta_1-\frac{\pi}{4}\right)+$$
$$\delta_2\,\epsilon^{-mx}\sin\left(pt-mx+\beta_2-\frac{\pi}{4}\right) \quad \ldots\ldots \quad (5)$$

where

$$m^2=\frac{2\pi p}{\rho}\cdot\frac{l_1}{l}\cdot\frac{d}{a}\cdot 10^{-9}.$$

It is easy to see that, where we have only one conductor in the slot, or the equivalent, as in Fig. 8, $\delta_1=\delta_2$ and $\beta_1=\beta_2$; but where there is more than one conductor in the slot, carrying current in the same direction, δ_1 and β_1 will differ from δ_2 and β_2 respectively, for all but the lowest conductor. The values of $\delta_1\,\delta_2\,\beta_1\,\beta_2$ for any conductor are determined by the two conditions:—

(1) That the total current flowing, or integral of current density over the cross section of the conductor $=d.b\,\Delta_0\sin pt$.

(2) That the cross induction at the root of the conductor, or where $x = 0$, equals

$$\frac{4\pi}{10} \cdot (n-1)\frac{d.b}{a}\Delta_0 \sin pt,$$

where $(n-1)$ is the number of conductors below the one in question.

In the single conductor case we have—

$$\left.\begin{aligned} c_1 &= \frac{mb\,\Delta_0}{\sqrt{\cosh 2\,mb - \cos 2\,mb}}, \\ \text{and} \qquad \tan\beta_1 &= \frac{\tanh mb}{\tan mb} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

for which the curves in Fig. 8 are plotted.

We do not propose to go into calculations for multiple conductors at length; those interested in the subject will do well to study A. B. Field's paper already referred to, where the necessary solutions are obtained for solid, stranded, and laminated conductors, as well as for a variety of types of former wound coils.

We have so far merely confined ourselves to the elementary mathematical considerations necessary for an intelligent grasp of what follows.

The important fact to determine is how much greater is the actual ohmic loss due to the ununiform distribution, than the nominal loss, or that calculated on the assumption of uniform distribution.

For this purpose we have only to consider the maximum values of the current at varying depths, and do not need to trouble about the relative phase relations. The maximum value of the current density at x, as derived from (5) and (6) is

$$\sqrt{2}\,mb\,\Delta_0\sqrt{\frac{\cosh 2\,mx + \cos 2\,mx}{\cosh 2\,mb - \cos 2\,mb}} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The values of the current density at different points of the conductor shown in Fig. 8 are plotted corresponding to the three cases $mb = 6$, $mb = 3$, and $mb = 1{\cdot}5$. If we take $\frac{d}{a} = 0{\cdot}61$, $f = 50$, then $m = 0{\cdot}8$, and the above values will correspond to depths of conductor 7·5 cms., 3·75 cms., and 1·875 cms. respectively. Where there are more conductors than one in a slot, current flowing in each in the same direction, these effects are greatly magnified in the upper conductors.

It must be borne in mind that the phase of the current is not the same at all points of the conductor, but a continuous change of phase occurs from one edge to the other. For example, in the case where $mb = 3$ the current at the outer edge (P Q) is 45° in front of the load current; while the current at the root of the slot lags 127°, making a total phase difference of 172° between the current at mouth and root. In Fig. 8 the values of the square of the current density have also been plotted, showing how enormously the loss-density increases towards

the outer edge of the conductor. The mean height of these loss-density curves, or what is the same thing, the ratio of the area of the actual to the nominal loss-density curve represents the coefficient of virtual increase of resistance of the conductor, or the ratio of the actual to the nominal ohmic loss.

This ratio will be the mean square value of expression (7) taken over the cross section, divided by Δ_0^2. Calling this value K, we have

$$K = mb \frac{\sinh 2\,mb + \sin 2\,mb}{\cosh 2\,mb - \cos 2\,mb} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

This value, derived from the equations of the single conductor case, will apply only to the bottom conductor, where there are more than one in a slot carrying current in the same direction.

In the case of several conductors one above the other, each carrying the same total current, counting the lowest 1, the second 2, and so on, it can be shown that :—

$$K_n = mb\left[\frac{4(n^2-n)(\cosh mb-\cos mb)(\sinh mb-\sin mb)+(\sinh 2mb+\sin 2mb)}{\cosh 2\,mb - \cos 2\,mb}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

It will thus be seen that the constant by which the nominal ohmic loss per cm. must be multiplied, in order to determine the actual loss in a given conductor, or the coefficient of increase of resistance, depends entirely upon the depth of the conductor, the frequency, specific resistance, and the ratios $\frac{d}{a}$ and $\frac{l_1}{l}$. If the length of the slot be great in comparison with the other dimensions, the latter ratio may be taken as unity for a solid conductor.

The formulæ (8) and (9) have been utilised for the calculation of curves in Fig. 9,* corresponding to $n = 1$, $n = 2$, $n = 3$, $n = 4$, *i.e.*, for cases where slots contain 1, 2, 3, and 4 conductors connected in series, current flowing in the same direction in each. The curves apply merely to that part of the conductors lying within the slot and show how many times the actual loss is greater than that calculated from Ohm's law.

As examples illustrative of the use of these curves we will take the case of a four-layer winding, the depth of each conductor being 1 cm., frequency 50. Let $\frac{d}{a}$ be 0·61; we have then $m = 0·8$.

Referring to the values of K corresponding to $mb = 0·8$ for the 1st, 2nd, 3rd, and 4th conductors respectively, we obtain the values 1·04, 1·3, 1·85, and 2·6, that is to say that while the nominal loss is increased by the idle current effect to the extent of 4 per cent. in the lowest conductor, it is increased 2·6 times in the topmost conductor.

When we find in any machine that the idle current loss largely exceeds the nominal loss, and bear in mind that the one increases

* These curves have been plotted from the results given in Mr. A. B. Field's paper already referred to.

while the other decreases with the copper section, we are naturally led to inquire whether an actual diminution of the amount of copper may not improve the efficiency.

Suppose q is the ratio of the active length of the conductor to the length of a half turn. Let us now keep a, d, C and all other dimensions

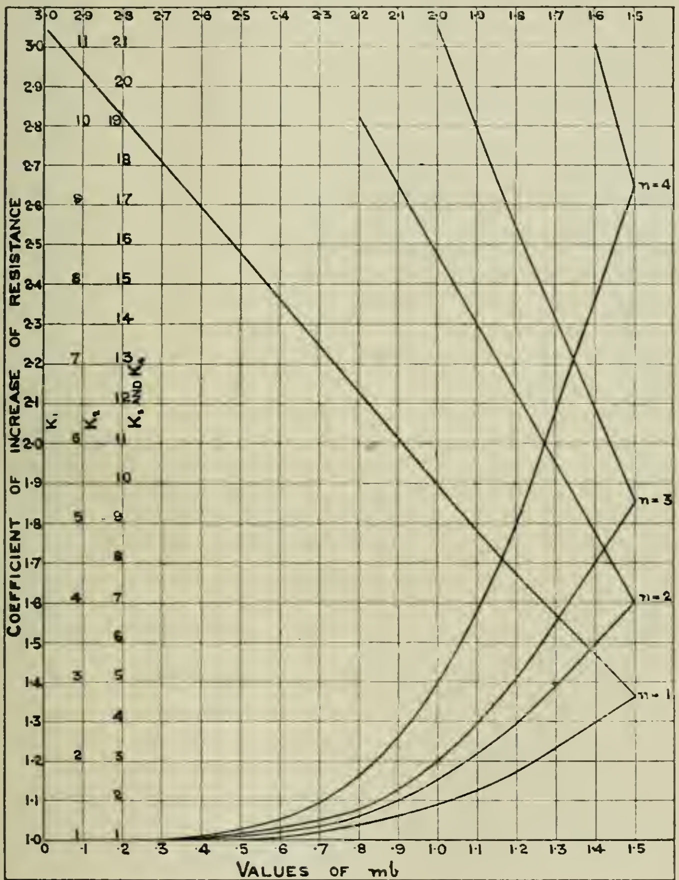


FIG. 9.

the same, varying only b, and for the present let us write $m = 1$. The nominal loss per cm. length is P/b, where $P = \frac{\rho C^2}{d}$ and the actual average loss per cm. is $\frac{P}{b}$ $(qK + (1 - q))$ where K is the coefficient corresponding to the value mb. If we plot $\frac{P}{b}$ vertically and b (or

mb where $m = 1$) horizontally, we obtain, of course, a rectangular hyperbola. If, now, we multiply each value of P/b by the corresponding value of $\{qK + (1 - q)\}$ we obtain the actual loss for each value of b, m being unity. This curve shows a minimum value, *i.e.*, there is a certain critical value of b giving minimum loss, and this

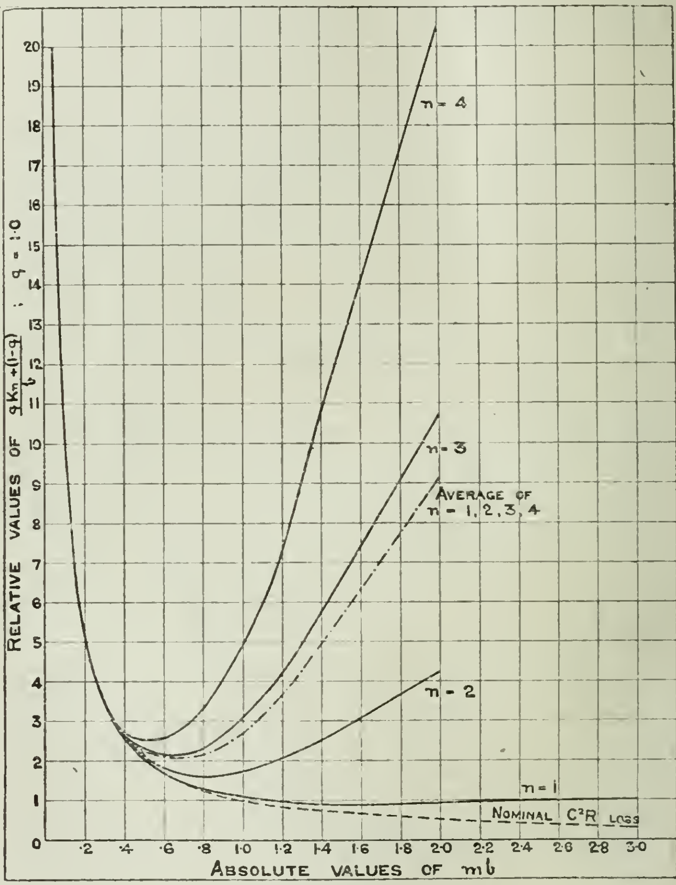


FIG. 10.

critical value is evidently independent of the value of C. If we double b, the nominal loss is halved, but if at the same time we halve m, the K coefficient remains unchanged, hence the curve last referred to applies equally well for $m = 0{\cdot}5$, if for any given point of the curve we multiply the reading of the abscissa by two, and the reading of the ordinate by a half. Or, if we consider that the abscissa represent values of *mb* instead of b, we do not need to change their scale.

Hence, we observe that for all values of m the point of minimum of the curve occurs at the same value of mb. Figs. 10 and 11* show these curves plotted for $n = 1$, $n = 2$, $n = 3$, $n = 4$, $q = 1$, and $q = 0{\cdot}5$.

These curves show the relative losses when m is kept constant at any value and b is varied, but it must be remembered that when m is

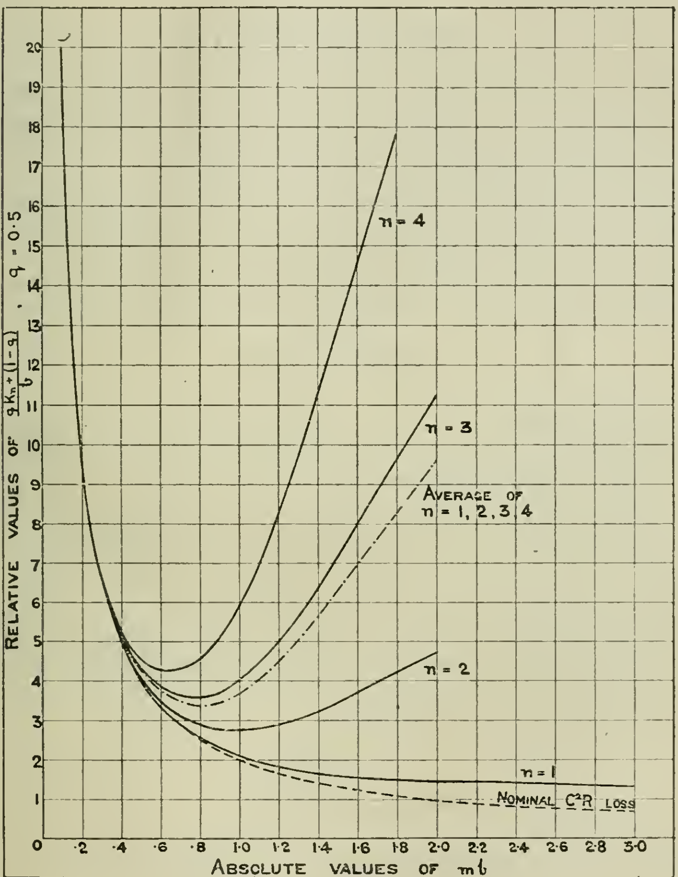


FIG. 11.

changed, the vertical scale is changed proportionately. They show, moreover, the value of mb at which minimum loss always occurs.

In Figs. 10 and 11 we have also shown the relative values of the nominal loss, as also the average value of the four curves $n = 1$, 2, 3, and 4.

* As mb increases K_n approaches the value $mb\,[2(n^2 - n) + 1]$: it follows therefore that the curves, if extended, will turn over horizontally and approximate to the straight line of which the ordinate is constant.

Referring to Fig. 10, where $q = 1$, *i.e.*, for the case where the whole length of conductor is active, it will be seen that no matter what current we require to take out of the conductor, the minimum loss for the lowest is obtained when $mb = 1{\cdot}4$, for the second when $mb = 0{\cdot}8$ and so on.

If, now, we put

$$f = 50,\ \frac{d}{a} = 0{\cdot}61,\ \frac{l_1}{l} = 1,$$

so that $m = 0{\cdot}8$, the critical depths of conductor are 1·75, 1, 0·8, and 0·7 cms. for the 1st, 2nd, 3rd, and 4th respectively. Any additional depth means an increase of loss and a waste of copper, no matter how large a current the machine may have to supply.

It also follows that if this critical depth be exceeded, an increase of specific resistance may decrease the loss, hence that the efficiency of the machine may actually improve as the temperature increases.

In Fig. 11 the curves correspond to $q = 0{\cdot}5$, *i.e.*, where half the total length per turn is active. The average-loss curve connects mb and

$$\sum_{n=1}^{n=4} \frac{q\,\mathrm{K}_n + (1 - q)}{4b}.$$

This curve obviously shows the critical value of b for a coil of four layers of solid conductor. For the same value of m as above, this critical value works out $b = 1$ cm.

Although we have determined the critical depth for a four-layer coil, provided the same section of conductor is used throughout, a little consideration will show that by grading the section of the conductor in the different layers a still better arrangement may be arrived at. Remembering that when $m = 0{\cdot}8$ a depth of 1 cm. has already passed the critical value of the outer layer, and has not yet reached that for the lowest layer, it follows that a more efficient arrangement will be obtained by transferring some of the copper from the outer to the inner layer.

A calculation will make this clear. If

$$q = 0{\cdot}5,$$

$$\frac{q\,\mathrm{K} + (1 - q)}{b} = \frac{\mathrm{K} + 1}{2b};$$

hence, from curves when $m = 0{\cdot}8$, $b = 1$ for all layers, we have—

$$(\mathrm{K} + 1)/2.$$

$$\left.\begin{array}{lcl} \mathrm{K}_1 = 1{\cdot}04 & \ldots & 1{\cdot}02 \\ \mathrm{K}_2 = 1{\cdot}3 & \ldots & 1{\cdot}15 \\ \mathrm{K}_3 = 1{\cdot}85 & \ldots & 1{\cdot}47 \\ \mathrm{K}_4 = 2{\cdot}6 & \ldots & 1{\cdot}8 \end{array}\right\} \text{Total loss in four turns} = 1{\cdot}36 \text{ times the nominal loss.}$$

Let us now suppose that the inner turn has a depth of 1·5 cms., the second 1 cm., the 3rd and 4th 0·75 cms., thus making up 4 cms. total depth of copper as in the last case, we have—

Layer.	b.	mb.	(K).	$(K+1)/2b$.	
1st	1·5	1·2	1·18	0·73	Total loss is 1·27 times nominal loss with uniform section.
2nd	1·0	0·8	1·3	1·15	
3rd	0·75	0·6	1·3	1·52	
4th	0·75	0·6	1·5	1·67	

Hence we see that, whereas with a graded section the loss is 27 per cent. more than the nominal loss in the uniform section, the increase is 36 per cent. with a uniform section, using the same total weight of copper.

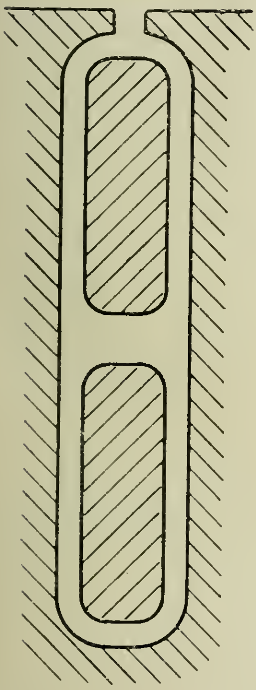


FIG. 12.

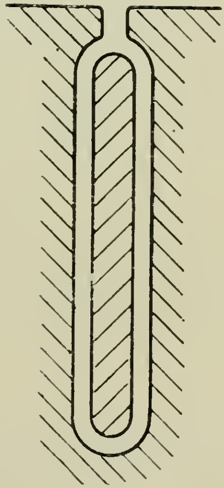


FIG. 13.

We will now apply some of the results to the first and second series of alternators supplied for Niagara. The slot and conductor dimensions are taken from Dr. S. P. Thompson's "Polyphase Electric Currents," 2nd edit., pp. 133, 135. Fig. 12 represents the conductor and slot for the first machines. Inserting the appropriate values of dimensions and frequency we have $mb = 1·97$, and referring to curve for $n = 1$, we obtain the value of $K = 1·88$, and for $n = 2$, $K = 8·1$, that is to say, that the actual loss in the active part of the lower conductor is 1·88 times, and in the upper conductor 8·1 times that calculated from Ohm's law.

Fig. 13 represents the slot dimensions of the second series of alternators—in this case *mb* works out at 2·7, and referring to the curve for $n = 1$ we obtain the value $K = 2·7$.

Taking the active proportions as roughly 50 per cent. of the total windings of these machines, we find that for the earlier machines, the actual loss in the whole winding was three times, and in the later machines 1·85 times the nominal loss. When we remember that these machines were supposed to have an efficiency of the order of 98 per cent., the relatively large extra loss due to idle currents assumes an additional importance. It is well known that the earlier machines ran exceptionally warm.

We will now investigate what economy might have been effected. Take the first series of alternators. If for the lower layer *mb* had been 1·4, and for the upper 0·9, the K values would have been 1·3 and 1·5 respectively. These values would have given $b = 2·42$, $b = 1·56$ cms. for the two conductors instead of 3·41 each, as is actually the case, and the total loss would have been 2·19 times the nominal loss with the 3·41 cms. conductors. Hence, the copper section might have been reduced in the proportion of 6·82 to 3·98, and the total loss in the proportion of 3 : 2·18. The weight of copper in the armature of each of these machines is roughly 3 tons.

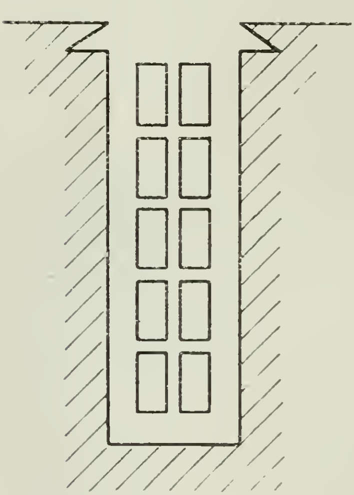


Fig. 14.

Taking the second series of alternators, we see from Fig. 11 that no gain of efficiency could have been effected by a decrease of the copper section, but a very considerable saving in copper might have been made at the expense of a small additional loss.

Thus, if instead of *mb* being 2·7 the conductor had been chosen so that *mb* was 2, a saving of copper in the proportion of 2·7 : 2 would have resulted, with an increase of the C^2R loss in the proportion of 1·39 : 1·45.

Fig. 14 represents the slot and conductor dimensions of the 3000/3500 k.w. 11,000 volt 2-phase alternators supplied by Messrs. Witting, Eborall and Company to the Metropolitan Electric Supply Company, Acton Lane Station. The frequency is 60, and it is interesting to note that the conductor depth chosen is just about the critical depth to give the best results. The actual ohmic losses work out at approximately 20 per cent. above the nominal. Had the machine been required for 4,400 volts instead of 11,000, and two conductors of 20 mm. depth been employed in the place of five conductors of 8 mm. depth, the critical depth in the outer conductor

would have been largely exceeded, and the actual loss would have been 1·98 times the nominal loss. The critical value of mb (taking $q=5$) is 0·9 for the second conductor, whereas in this case the value of mb would have been 1·55.

In determining slot and conductor dimensions there are, of course, other important factors which need due consideration. For example, the heat generated in the active part of the conductor is, to a large extent, conducted to the end connections at which it is dissipated by ventilation and radiation. A large cross-section of conductor forms a better conductor thermally, and may tend to reduce the maximum temperature within the active portion. Again, it has been urged that a deep conductor is sometimes advisable for mechanical considerations owing to the very great mechanical forces which may be exerted on the end connections, and yet again, the suggestion has been made, that a certain amount of idle current in the conductors is useful, in that it reduces the reactance of the whole winding.

We shall now briefly consider these three points :—

If we suppose that the copper within the iron armature is everywhere hotter than the iron itself, it is clear that there can be no transference of heat from *iron to copper*. By assuming that the whole of the heat generated within the active conductor is conducted to the end connections, we can readily determine the higher limit of the excess of temperature at the hottest part of the conductor within the armature, over the temperature of the conductor just outside. The heat generated per second per centimetre length of active conductor is

$$\frac{K_n C^2 \rho}{bd}$$

watt seconds, so that the total heat which traverses any section of the conductor λ centimetres from the middle of the armature is $K_n C^2 \rho \lambda / bd$. This may also be expressed in terms of the temperature gradient as

$$-\eta \frac{dT}{d\lambda} \times bd$$

where η is the heat in watt-seconds conducted per second along a bar of unit cross-section, with a temperature gradient of 1° C. per centimetre length. For copper we may write $\eta = 4$ watt seconds.

Hence we have

$$-\frac{dT}{d\lambda} = \frac{K_n C^2 \rho}{4 b^2 d^2} \lambda$$

and

$$T_1 - T_0 = \frac{K_n C^2 \rho l^2}{32 b^2 d^2} = \frac{K_n D^2 l^2 \rho}{32}$$

where T_1 = Temperature in centre of armature, degrees C.
T_0 = " just outside of armature, " "
l = Length of armature, in cms.
D = Nominal current density, amperes per sq. cm.

As an example, let us take $D = 200$, $\rho = 1 \cdot 9 \times 10^{-6}$, $l = 100$, $K_n = 2$; we have $T_1 - T_0 = 48°$ C.

This is the higher limit of temperature excess obtained on the assumption that no heat leaves the conductor laterally, but that the whole is conducted longitudinally to the end connections. The maximum excess depends upon the square of the length of the armature, and other things remaining constant, upon K_n/b^2.

If we examine the curves in Fig. 10 for K_n/b and mb, we see at a glance that for the lowest conductor K_n/b^2 will continuously decrease

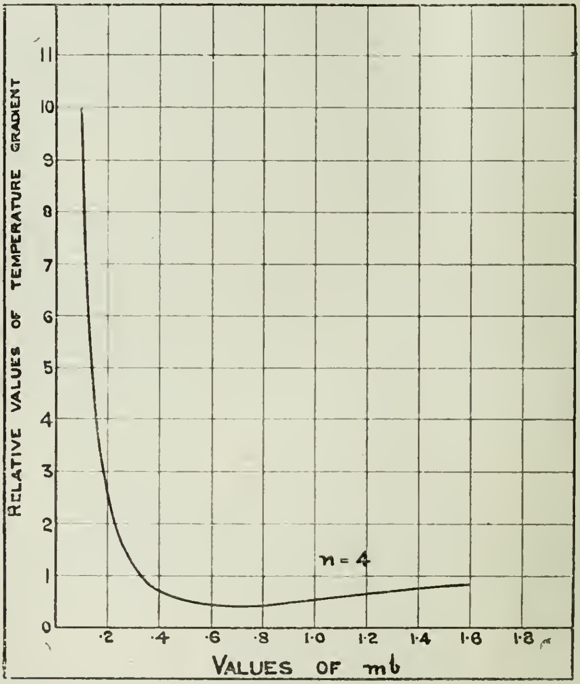


FIG. 15.

as b increases; this is evident, since K_1/mb approximates more and more to unity as b increases, hence, in this case, the excess temperature may be kept down by increasing b, although at the cost of a greater loss in the active portion.

If, however, we plot K_4/b^2 and mb, we find that this curve Fig. 15 has a minimum value corresponding to $mb = 0 \cdot 8$, which means that this value will give the minimum temperature gradient.* It is, of course, of

* The shape of this curve is interesting. For $b = 0$ the value is ∞; the curve then descends to a minimum value, rises again, and thereafter dwindles away to zero as b becomes ∞. When b is great the curve approximates to the law

$$m \frac{2(n^2 - n) + 1}{b} = y;$$

where y is the ordinate and mb is the abscissa.

utmost importance to so proportion the conductors that they will stand heavy surges and short circuits without liability of damage, but the above calculation shows, that where there are several conductors per slot, it may be advantageous to limit the depth of the upper conductors on account of the temperature gradient, as well as on account of the idle current loss.

Granting the relation between thermal and electric conductivities in the more conducting metals, as experimentally determined by Kirchhoff and Hansemann, Lorenz, and others (although the relation has been denied by other experimenters), it does not appear that any advantage is to be gained from the temperature gradient point of view by using a material of lower conductivity than the best copper. If, however, the active portions of the armature conductors be well ventilated by air-ducts and the iron be relatively cool, so that a sideways conduction of heat occurs from the conductors to the iron, the above considerations of temperature gradient are inapplicable, and it is to be observed that, with a given depth of conductor, the actual losses may, in some cases, be appreciably reduced by the use of a material of high specific resistance. Such would be the case in Fig. 12, top conductor.

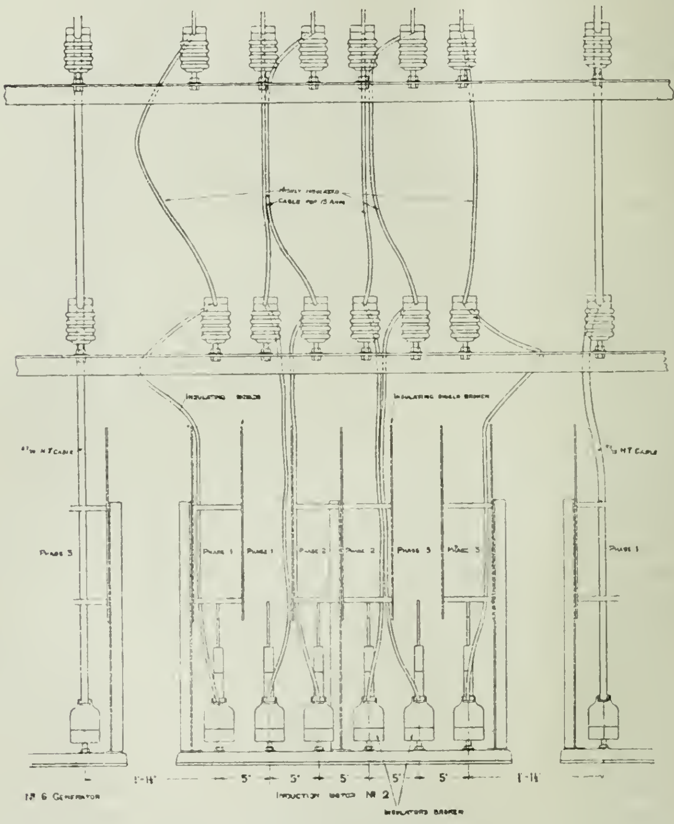
The enormous forces which are sometimes called into play between conductor and conductor are scarcely credible until one has seen the destructive effects of heavy short-circuits. When an arc is suddenly formed and a terrific amount of power is poured into the flame, one can almost imagine the explosive action that must take place ; thus Mr. Steinmetz reckons in the *Journal of the American Institute Electrical Engineers*, vol. xxiv. p. 590, that the energy of 100,000 k.w. applied during only $\frac{1}{10}$th second equals the explosion of about half a pound of dynamite ; yet it is difficult to realise the mechanical force excited between conductor and conductor when no arc takes place. We can best illustrate the point by a description of actual phenomena.

A serious trouble which has been experienced with the turbo-generators in the Chelsea Generating Station of the London Underground Railway, is the bursting of the end connections when a " short " occurs. The machines are 4-polar and the end connections of the armature, which is stationary, therefore bridge across 90°. The end connections lie one up against the other in the usual manner, and those of each phase are all strongly bound together to form a compact whole. They are otherwise unsupported. On the occurrence of a " short " the bindings burst and the end connections fly out with all the appearance of an enormous internal force wrenching them apart, usually necessitating the complete re-winding of the armature.* As a second instance, we will quote the words of Mr. H. G. Stott, who was the Superintendent of

* Several experimenters have found that the initial rush of armature current that occurs when a large fully excited alternator is suddenly short-circuited is many times the nominal short circuit current after the steady state has been reached, and that this abnormal current may last several seconds, probably depending upon the time-constant of the field magnet circuit. It would be out of place for the writer to dwell further upon this matter here, more especially as he learns that the subject is being investigated by a prominent member of our Local Section, who proposes before long to place the results of his investigation before this Institution.

the Manhattan Elevated Railway System of New York in 1903, when a phenomenal high power surge occurred in the system (see *Journal of American Institute of Electrical Engineers*, vol. xxiv. p. 579).

"One of the six generators operating in multiple, short-circuited near the terminals, conductors on two turns of the winding being



H.T. INDUCTION MOTOR PANEL

DISPLACEMENT OF CABLES DUE TO LOCAL SHORT CIRCUIT

FIG. 16.

driven out until they struck the iron of the frame of the generator, *i.e.*, the armature bars, which are 2 in. × $\frac{1}{8}$ in., three in each slot, were bent edgewise for over six inches, showing that the force bending them probably amounted to at least 3,000 or 4,000 lbs."

Mr. C. P. Steinmetz, describing the same incident, says :—

'On generator No. 4, 28 armature bars and 11 connectors at the terminals of the machine were broken, bent, or badly burned. On

generators 2, 5, 6, 7, some of the armature bars of phase C were also slightly bent, showing excessive current."

Lastly, we may mention an occurrence in the Electricity Works of our own City of Manchester. By the courtesy of our Chairman, the City Electrical Engineer, we are enabled to publish Fig. 16, which represents the appearance of some of the cables at the back of a switchboard, after a sudden rush of current. The thicker cables on the outside are 37/15 highly insulated, while the smaller cables, which show the greatest amount of distortion, are arranged to carry about 10 amperes and also highly insulated. All cables were tightly stretched between insulators from 2 ft. to 3 ft. 6 in. apart. The mutual attractions and repulsions are well illustrated by the shapes of the cables. Insulators 5 and 6 were snapped off, and the insulating shield marked S consisting of ¼-in. asbestos millboard was cut clean through. This case is interesting on account of the absence of any quantity of iron in the neighbourhood to increase the magnetic effects.

It appears to us that, considering 2-in. solid conductors may be bent edgewise in the disastrous manner that happened on the Manhattan system, it is useless to propose to make them self-supporting. Rather should engineers take the occurrence as a lesson to suitably support the end connections by means of substantial clamps at frequent intervals, and thus leave themselves unfettered by these considerations in the choice of their conductor. Indeed, unless we admit this principle, we should be forced to advocate the use of deep solid conductors, and the avoidance of all stranding and other devices which decrease the mechanical strength of such conductors.

Lastly, it will be obvious that the smaller the conductor in an open slot the less must be the reactance due to the cross flux, and that to advocate the use of solid conductors at all in place of stranded bars for the sole purpose of limiting the reactance is false economy. Surely the money represented by the increased losses would be better expended in a more generous design of machine resulting in the desired improvement of regulation.

We have so far only dealt with the lamellar effect in connection with alternating current machines. When we consider, however, that the current flowing in the armature conductors of direct-current machines is, in reality, an alternating current, we see that the above results, with certain modifications, are also applicable to direct-current machinery. We do not propose to enlarge the scope of this paper unduly by entering upon a lengthy discussion of the critical depth, temperature, gradient, etc., of direct-current armature conductors, but merely to indicate the lines upon which these considerations may be investigated. Confining our attention to a particular armature conductor of a direct-current machine, we remember that the current is flowing in one direction when the bar is passing under a N-pole, and in the opposite direction when passing under the S-pole. The change of direction is effected during the commutation period. The current value at any instant during this period is somewhat indefinite, but the period is of relatively short duration. Fig. 17 may be taken as repre-

senting the current in any armature conductor where the dotted portion is substituted for the unknown which occurs during commutation.

If, as an approximation, we take the current in each bar as being equivalent to that shown in Fig. 18, the case is capable of fairly exact

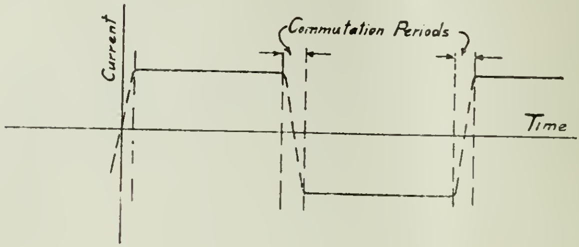


FIG. 17.

computation. Let C be unity, then the current at any instant is given by—

$$\frac{4}{\pi}\left(\sin pt + \frac{1}{3}\sin 3pt + \frac{1}{5}\sin 5pt + \text{etc.}\right)$$

were $p = 2\pi f$. We thus have a number of sine-wave alternating currents of differing frequencies flowing in each bar, and as already

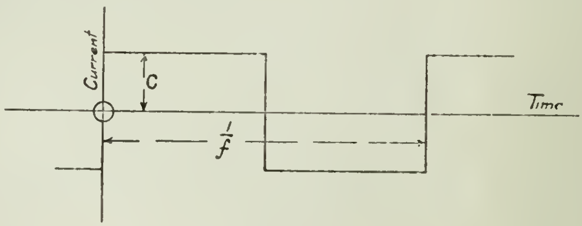


FIG. 18.

pointed out, we can calculate the loss due to each, as if it existed separately. There is, therefore, no difficulty in applying our previous curves and formulæ. Take the case of a 6-pole 500-r.p.m. direct-current generator, f will be 25 cycles per second. We must, therefore, calculate the value of mb for $f = 25, 75, 125$, etc., and calling the corresponding K_n-values respectively ${}_1K_n$, ${}_3K_n$, ${}_5K_n$, etc., where the suffix determines the position of conductor in slot (*i.e.*, 1st, 2nd, or nth), and the prefix determines the frequency term of the Fouriers series.

The coefficient of increase of resistance for the nth conductor carrying the current shown in Fig. 18 will then be given by the expression—

$$\frac{8}{\pi^2}\left[{}_1K_n + \frac{1}{9}\left({}_3K_n\right) + \frac{1}{25}\left({}_5K_n\right) + \text{etc.}\right]$$

In general the K values for solid conductors of direct-current

machines will be greater than those for conductors of the same depth in alternating-current machines running at the same speed and having the same number of poles, because in the direct-current machines the current is largely composed of higher-frequency terms, and secondly, since direct-current machines are generally constructed for lower voltages, less space will be occupied in the slot with insulation. Fig. 19 represents a 2-layer winding in a direct-current armature. The K value of the active portion of the upper conductor calculated from the first seventeen terms of the above series is 2·5, f being taken at 25 cycles per second. The K value for the lower conductor is 1·26, and for the whole winding 1·44, assuming as before $q = 0·5$.

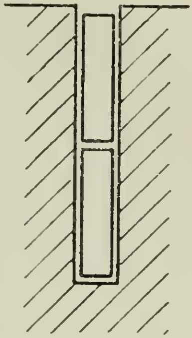


FIG. 19.

Unfortunately this series is not very rapidly convergent.

The K values for the higher-frequency terms may be calculated from the expression—

$$mb\left[2(n^2 - n) + 1\right].$$

In the armature of a rotary converter the effect is still more pronounced, since the higher-frequency terms are more predominant.

As an example, let us consider a singly re-entrant series winding of a 3-phase continuous converter. If V = direct-current voltage, *a.c.* voltage between rings = 0·613V. Let C be the direct current flowing in each conductor, and C_1 the amplitude of the (sine-wave) current input in each conductor; then, if we assume a 95 per cent. efficiency exclusive of excitation and unity power factor, we have—

$$3 \times ·613V \times \frac{C_1}{\sqrt{2}} \times 0·95 = 2VC,$$

or—

$$C_1 = 1·61C.$$

The actual current flowing in a conductor at the centre of a phase winding will then be, assuming instantaneous commutation—

$$\frac{4C}{\pi}\left[\sin pt + \frac{1}{3}\sin 3pt + \text{etc.}\right] - 1·61C\sin pt;$$

from which it is evident that the higher-frequency terms will be relatively more predominant than if the machine were run as a direct-current generator.

The expression for the current at any other part of the armature can be found in a similar manner, and from the data previously given the K values for any of these cases may be calculated.

The conclusions arrived at in this communication will not be much modified by saturation of the armature teeth, as might be thought at first.

If in Fig. 8 we consider the iron on both sides the slot highly

saturated, the amount of the cross flux will not produce any important change in the degree of saturation. Thus, the magnetic force acting from b to c will be equal and opposite to that acting from d to a, hence, in spite of saturation we can still take the induction density from a to b as approximately $\frac{4\pi}{10}\frac{C}{a}$ times the current enclosed within the path *abcd*. Similarly, the results will not be much affected by a bridge of iron across the mouth of the slot, provided its section is very small compared with the section of the tooth. It is unlikely that the saturation of the bridge will be carried much above 20,000 per sq. cm., and if the tooth section be twenty times that of the bridge, this flux would represent a density in the tooth of only 1,000 lines, or considerably less if neighbouring slots carried equal currents in the same direction. It is clear that under these circumstances the magnetic force in passing from one side of the slot to the other through iron *viâ* the root can be but small.

If, on the other hand, the conductor were buried in the iron, there would be no cross flux at all, and the interior surface of the hole would be magnetically an equipotential surface.

APPENDIX.

To prove that, if current be flowing along a conductor, the minimum loss occurs when the "natural distribution" (as later defined) obtains, and that any current distribution is identical with a system of idle currents superposed upon the natural distribution.

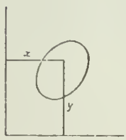


FIG. 20.

The figure represents the cross section of a conductor in which current is flowing at right angles to the plane of the paper.

Suppose that the specific resistance is not everywhere the same, but is a function of x and y denoted by $\phi\,(x\,y)$. (Fig. 20.)

Since current is flowing longitudinally only, cross sections parallel with the plane of the paper are equipotential surfaces. If no disturbing influences are brought to bear, the distribution of current density will be, at the point $x\,y$,

$$\frac{V}{\phi(xy)},$$

where V is the potential difference between two planes 1 cm. apart.

The total current flowing will be—

$$\int\int \frac{V}{\phi(xy)}\,dxdy,$$

the integration extending over the cross section of the conductor.

Suppose now that, due to some unknown cause, this current density

distribution is disturbed, so that while the total current flowing remains the same,

$$\frac{V}{\phi(xy)}$$

no longer represents the distribution. Let the new distribution be $f(xy)$. Since the total current flowing is the same in the disturbed as in the undisturbed condition, we have—

$$\int\int f(xy)dxdy - V\int\int\frac{dxdy}{\phi(xy)} = 0.$$

Now the current density at the point xy may be divided into two component parts, viz.:

$$\frac{V}{\phi(xy)} \text{ and } f(xy) - \frac{V}{\phi(xy)}.$$

The latter, however, represents a system of idle currents, since its surface integral over the cross section is zero, *i.e.*, it constitutes a system of currents which do not add to the *total* current flowing in the conductor.

The total ohmic loss per unit length is—

$$\int\int [f(xy)]^2\phi(xy)dxdy.$$

We now subtract from this the expression—

$$2V\int\int\left[f(xy) - \frac{V}{\phi(xy)}\right]dxdy$$

which, as we have already seen, has zero value, and we can write the total ohmic loss as—

$$\int\int\left[f(xy)^2\phi(xy)dxdy - 2V\int\int f(xy)dxdy + 2V^2\int\int\frac{dxdy}{\phi(xy)}\right.$$

which is algebraically identical with the form—

$$\int\int\frac{V^2}{\phi(xy)}dxdy + \int\int\left[f(xy) - \frac{V}{\phi(xy)}\right]^2\phi(xy)dxdy.$$

Now the first term represents the loss in the undisturbed condition, while the second obviously represents the ohmic loss of the idle currents. This latter has always a positive value, hence the minimum ohmic loss occurs when the idle current system has zero value, and the current follows the distribution represented by—

$$\frac{V}{\phi(xy)}.$$

This is the "natural distribution." We see that when any other distribution occurs, it can always be considered as identical with the natural distribution with some system of idle currents superposed.

The total loss is the sum of the losses due to each reckoned separately.

Instead of a single conductor with varying specific resistance, we might have a group of conductors connected in parallel, having differing lengths, cross sections, etc., and the theorem would equally well apply.

DISCUSSION.

Mr. Pearce. Mr. S. L. PEARCE (Chairman): Although the paper is chiefly for designers, there are many points of practical importance, from which an engineer in charge of large alternating systems can learn much. The latter part of the paper, in which Mr. Field touches on the problems involved in the enormous forces exerted on the end windings of alternators when subjected to shorts or bad phasing, is exceedingly interesting. I think I am right in saying that manufacturers have not until quite recently taken into account these forces which produce distortion effects, in the design of alternating machines. Up to a recent date machines were built with their end windings totally unsupported from the stator frames.

Mr. Frith. Mr. J. FRITH: I have always hitherto understood the term "idle current" to mean current at right angles to volts.

Mr. Walker. Mr. MILES WALKER: All engineers concerned with the design of electrical machines have for long been wanting to know exactly how much eddy current to expect in straps of different depths. It has been possible by a rough graphic construction to arrive at an approximate value for the loss due to the eddy current. But by means of these beautifully simple curves we can in the course of a few minutes figure out the eddy-current loss exactly for any given case, and can find at once the most economical depth of strap to use under any circumstances. The question naturally arises, Are these curves correct? Do they really give the additional losses found in practice? In 1903 the Westinghouse Company, realising the importance of eddy-current losses, made a number of experiments to find out their values in different cases. The trials were made by winding coils with different kinds of straps in the same armature core, and measuring the watts supplied when an alternating current was passed through the coils. The iron loss was separately measured and taken into account. The report of Mr. F. D. Newbury upon the results of the tests gives a number of curves for the losses with different straps and at different frequencies. Taking two good cases for comparison—one at 25 cycles and one at 60 cycles—the results agree very closely with the calculations from the formula* given by Mr. A. B. Field. It has been said that the Chelsea 5.500-k.w. turbo-generators have had their windings bent by being short-circuited. The facts are that these machines were thrown out of phase when running in parallel with other generators. These conditions are very much worse than a short-circuit. The forces might be almost four times as great as a simple short-circuit. The windings were braced, but the bracing was not sufficient for the

* *Proc. Amer. Inst. Elec. Eng.* vol. 24, p. 659.

difficult conditions. They are now being braced in a much more solid way. Mr. Walker.

Dr. C. C. GARRARD: I venture to criticise the author's definition of "idle current." To my mind the term has already a certain fixed meaning and represents the wattless component of an alternating current, *i.e.*, that component which is at right angles to the voltage. The author's definition is, however, an extremely wide one, and includes all currents which waste energy to the extent of their C^2R loss, including even the actual working current, and a paper on "idle currents" under this definition would cover the whole field of electrical design. I suggest, therefore, that the proposed new definition of idle current should not be adopted, as, if it were, it would tend to cause confusion as to a term which at present has a definite significance. I think one of the most valuable parts of the paper is the proof that any system of currents can be regarded as an "idle current" distribution superimposed upon the distribution which would obtain with continuous current. While for mathematical investigation, of course, this is of the utmost importance, it does not always represent what actually takes place in the circuit. Consider the case of two equally-rated transformers working in parallel which have different impedance values, so that they do not bank properly. The current does not divide up equally between the two transformers, but divides so that the drops due to the different impedances is such that the terminal voltages of the two transformers become equal. The sum of the virtual values of the currents in the two transformers is equal to the virtual current in the outside circuit. There is no idle current circulation at all. I think this consideration can be applied to other problems, such as a number of circuits connected in parallel. The distribution of current in the various circuits is always a natural one. In the direct-current problem simply the ohms have to be taken into account; in the alternating-current problem the impedance and mutual induction between the conductors determine the volt drops in the conductors, and the condition of equilibrium is that the volt drops of the various conductors connected in parallel are all equal. A massive solid conductor can be considered from the same standpoint as a bundle of very fine parallel wires. The question of eddy-current losses in transformers is of great practical importance, and in their design care has to be taken to eliminate all such causes of loss, or, where they are unavoidable, to allow for them in the design, so that the required efficiency and temperature rise may be obtained. Several cases have come under my notice. One consisted of a 1,000-ampere transformer, wound with copper strip of a total cross section of $1\frac{1}{2}$ sq. in. The copper loss in this transformer was 44 per cent. larger than that which would be calculated from the ohmic resistance of the windings, this being the eddy-current loss in the heavy current winding. Another case was a core type transformer made for a special purpose. It had four coils per leg, two primary and two secondary, all having the same mean turn. It will be seen that the impedance of the middle coils was less than that of the end coils. Dr. Garrard.

Dr. Garrard. This results in an eddy-current effect in that when the coils are connected in parallel the middle coils take more current than the end ones. The result is that the efficiency of the transformer is not so good when the coils are connected in parallel as when connected in series. In order to avoid eddy-current losses in the coils of transformers it is sometimes recommended to wind them with stranded conductor for the larger currents. As stranded conductor is very much more costly than strip, it is more economical to use the latter, providing no losses are introduced thereby. I have found, however, in core type transformers, that for currents up to at least 500 amperes, if the winding be made of strips, about 0·5-in. by 0·1-in. section, connected in parallel, and proper precautions be taken, no appreciable eddy-current loss takes place in the windings—*i.e.*, the copper loss is the same under working conditions as calculated from the ohmic resistance. It may be asked what is the good of using strips in parallel, as, if the strips are soldered together at the ends, as is the case generally, they are equivalent to a solid conductor. I do not think this is correct, however, but that in a solid conductor local eddy-current losses will occur owing to the fact that the leakage field is not by any means a uniform one. The lines leak out between turns and between layers in a very irregular fashion, and the lamination of the conductor prevents such losses as would otherwise occur. Regarding alternator windings, I am under the impression that nowadays stranded conductor is generally used for the winding, owing to it being easier to wind than solid conductor. With stranded conductor, of course, the conclusions arrived at in the paper would be very considerably modified.

Mr. Peck. Mr. J. S. Peck: Mr. Field has dealt in his paper with the question of idle currents in armature conductors. Difficulties of the same nature, however, have been encountered in the design and operation of transformers. In 1892 the Westinghouse Company designed a small transformer which was intended to have an extremely high efficiency. In order to keep down the copper losses, the low-tension winding was composed of large rectangular copper strap. When the transformer was put on test, the designers were greatly surprised to find that the low-tension winding reached an excessively high temperature. After some consideration it was decided that the excess heating was due to eddy-current or idle-current loss in the rectangular strap, the currents being set up by the leakage magnetic field through the windings. It was realised that this was a matter little understood, but which would have great weight in the design of large transformers. A series of investigations were therefore carried out, using wires and straps of various dimensions placed in different ways in magnetic fields of different densities and frequencies. From these tests, supplemented by theoretical considerations, curves were plotted showing what idle-current losses might be expected in copper conductors under different conditions. These curves enabled the transformer designer to choose such conductors as to avoid excessive losses due to local currents set up within the conductor. It was found, however, that parallel

conductors—even though insulated throughout their entire length— were subject to much the same idle-current losses as solid conductors unless properly transposed. Another difficulty which has been frequently encountered is due to the attempt to operate in parallel coils which are not located in symmetrical magnetic positions, so that on account of the difference in the leakage magnetic field cutting the two coils, unequal voltages are induced. Once the reason for this inequality is understood, no trouble should be encountered in designing a transformer to avoid this difficulty, but until it was understood some very puzzling results were obtained. I believe that no trouble occurred caused by the displacement in the end windings of generators and transformers until units of very large size were installed. A certain amount of trouble was encountered with the Niagara generators' winding, caused by displacement of the coils in the event of one machine being thrown in parallel with other machines when out of phase. Methods were devised for bracing this winding, and great care is given to this bracing in all machines of large capacity. In the Chelsea generators referred to by the author, the coils were braced in a manner which it was thought was amply sufficient. It was found, however, that when one machine was thrown in parallel out of phase with other machines, the forces were so enormous that the supporting blocks were crushed and torn loose from their supports. Shortly after the first Niagara machines were installed, a short circuit occurred on the secondary circuit of a 200-k.w. transformer. An examination of the transformer showed that when the short occurred the outside end coils which project beyond the iron core had been bent over at right angles and flattened against the end frames which held the laminations together. These coils were wound with large rectangular wire, several wires in parallel, so that an enormous force must have been required to bend the coils into the position in which they were found. After this accident steps were taken to brace the coils of large transformers in order to prevent their being thrown out in case of sudden short circuits. In very large transformers having extremely close regulation it is necessary to take the greatest care in bracing the coils in every direction, as the currents which flow through the coils of such a transformer in the event of a short circuit may be 20 to 40 times the normal, thus producing forces between the coils 400 to 1,600 times the normal force. Mr. Peck.

Mr. M. B. FIELD (*in reply*): I think that the discussion calls for very few further remarks on my part. I am naturally glad to hear from Mr. Walker that tests carried out by the Westinghouse Company fully confirm the theoretical calculations. I may say that my brother, Mr. A. B. Field, has also, since this paper was written, carried out a fairly elaborate set of tests to accurately determine the losses in slot-wound conductors, and has fully demonstrated the correctness of the theory. Mr. Field.

I wish to acknowledge my error in stating that the end connections of the Chelsea generators were unsupported. I based my remarks upon my own observation, and although I examined these machines on

Mr. Field. various occasions, and in various stages of winding, I cannot recollect having seen any supports to the end connections.

Dr. Garrard has somewhat misinterpreted the meaning I attached to the term "idle current." It in no way includes the working current (see definition under heading: "Explanation of Symbols and Expressions"). Dr. Garrard is further not correct, in my opinion, in stating that the subdivision of current among various branches, as determined by their relative impedances, is the natural distribution, if the same meaning be attached to the term "natural distribution" as in the paper. The "natural distribution" is that which gives minimum ohmic loss. There is only one distribution which gives the minimum ohmic loss; any other distribution must involve a greater loss, and it is equivalent, as stated, to the distribution giving minimum loss, or what I have termed the "natural distribution," plus a distribution of idle current. Take two current paths in parallel of equal resistance and having no inductance, and assume a given alternating current flowing. This will divide equally between them, giving minimum ohmic loss. Now, add inductance to one path without altering the ohmic resistance of either. With the same total current flowing it will be found that the current in each branch differs from the original value, and the total ohmic loss will be increased. I maintain that the current distribution and the losses will now be the same as if the original (natural) distribution existed, together with a certain superposed current circulating between the two branches. In the case of transformers "banking," mentioned by Dr. Garrard, if the resistances are equal and currents unequal the distribution is not the natural one as defined in the paper, and there certainly is an idle current present.

Dr. Garrard's remarks "that the impedance and mutual induction between the conductors determine the drop of volts in the conductors, and the condition of equilibrium is that the volt-drops of the various conductors connected in parallel are all equal," are perfectly true; but I do not see that this has any bearing upon the point as to whether the particular distribution which results therefrom is that which gives the minimum ohmic loss or not.

Fig. 5 with context illustrates clearly the existence of an idle current where two paths of equal resistance are connected in parallel and the currents are not equal. Both here and in the appendix the reasoning applies at any and every instant, and is therefore true of continuous, alternating, and varying currents of any description. As far as I can see, the theory is quite rigorous. I think Dr. Garrard must be applying a different interpretation to the term "natural distribution" from what I have done. I also observe that later in his remarks Dr. Garrard points out that on a certain transformer where various windings were connected in parallel, having unequal impedances, an unequal current distribution, or "eddy current effect," resulted, and I cannot quite reconcile Dr. Garrard's previous statements with this one.

Mr. Peck's remarks regarding the bracing of alternator and transformer coils will be of great interest to all designers of heavy electrical machinery.

DUBLIN LOCAL SECTION.

ELECTRIC CONVEYING MACHINERY, WITH SPECIAL REFERENCE TO THE ZAMBESI GORGE.

By John Ritchie.

(*Abstract of Paper read January* 18, 1906.)

Electric Cable Conveyors.—In the year 1884 the late Professor Fleeming Jenkin read a paper before the Society of Arts on a new method of conveying goods by electricity, to which he gave the name of Telferage. This was the principle of electric traction on a single rail or rope, the motor forming part of the train or carriage carrying the load.

For a good many years little headway was made, many difficulties connected with the application of the earlier forms of electro-motors presenting themselves, and in connection with the propelling mechanism, various complications of horizontal and vertical gripper wheels were considered necessary to obtain adhesion.

Another difficulty arose more particularly with a wire-rope cable of long span; this was the impossibility of maintaining a uniform degree of tension on the rope.

This defect is entirely eliminated in the system of conveyor which has been introduced into this country by Messrs. E. Scott & Mountain, Ltd., of Newcastle-on-Tyne. A constant strain is put on the cable by anchoring it at one end, passing it over a fixed tower, and at the other end fixing it to a set of oscillating sheer legs, to which are attached counterweights. By the action of these sheers the deflection is increased with the load, but as the load decreases the strain on the cable is maintained, owing to the sheers setting back and thereby taking up the sag. The sheers are set at an angle of 45°.

Large numbers of these useful conveyors are now in use, but the one I wish particularly to describe is that constructed to convey the material for the construction of the great bridge across the Zambesi.

When the Cape to Cairo Railway was decided on it was necessary to cross the River Zambesi, and it was decided by the engineers that the river should be crossed at the great Gorge, a short distance below the Falls. The river here is 650 ft. wide between the banks, which are 400 ft. above the water level. Under these circumstances it was manifestly impossible to use scaffolding, and it was decided to construct

an arched bridge, built out from either side. The Cleveland Bridge and Engineering Company, of Darlington, obtained the order for the bridge, and resolved to adopt an electric conveyor of the type described.

Up to this time the heaviest conveyor on this principle was of 4 tons capacity, but owing to the enormous quantity of material to be carried across the river until the bridge was finished, not only for the bridge but for the extension of the railway beyond, estimated at 50,000 tons, it was decided to make a conveyor for 10 tons.

The author was entrusted with the modification of the design to adapt it for a 10-ton conveyor, and also with the construction of the mechanical portion of the hoisting and travelling apparatus. Fig. 1 shows a section of the Gorge with the conveyor in position. The fixed tower is seen at one side, and the oscillating sheers at the other, with the cable stretched between. The span is 870 ft. The cable is of the finest plough steel, $2\frac{9}{16}$ ins. in diameter, and the sag in the centre, with a load of 10 tons, is 43 ft. 6 ins.

The conveyor is in some respects similar to the usual type, but the necessity of using runway ropes, fall-rope carriers, etc., as a means of hauling the load from one end of the supporting cable is done away with, and the special self-containing hoisting and travelling apparatus and motor only requires a copper trolley wire to convey the current to it from the generating station on the bank. The complete hoisting and travelling apparatus is suspended from two travelling wheels running on the rope. These wheels are geared so that the whole weight is available for adhesion. The wheels are of cast steel, and have cast-iron liners, turned to fit the rope. These were made of rather soft cast iron, and easily renewable at a small cost, so as not to cause undue wear on the rope.

On a steel frame, hung down from the axles, is mounted a single electro-motor of 30 H.P., the normal speed being 500 r.p.m., but with light loads, being series wound, it can be run up to 1,000 r.p.m.

The current is conveyed to the motor by a copper wire, which runs parallel with the main cable and collector pulley; the return is by the main cable. The end of the motor shaft carries a forged steel pinion sliding on a feather, and arranged to engage with either of the spur wheels, one for the hoisting and the other for the travelling gear.

There are two wrought steel hoisting barrels, grooved for wire rope; these barrels are operated by steel worms gearing into phosphor bronze wheels keyed on the barrels direct. The barrels themselves are without shafts, and revolve on a ring of steel balls, thus reducing the friction in working to a minimum. Automatic electric brakes are fitted to both hoisting and travelling gears; both motions are also fitted with foot brakes. The steel supporting frame is pivoted round the centre shaft of the travelling gear, which thus secures its hanging perfectly plumb, at whatever angle the main cable may be.

The centre of gravity is carefully determined by the position of another swivelling pin in the lower portion of the frame, so that the relative position of the rope is not altered, whether the conveyor is

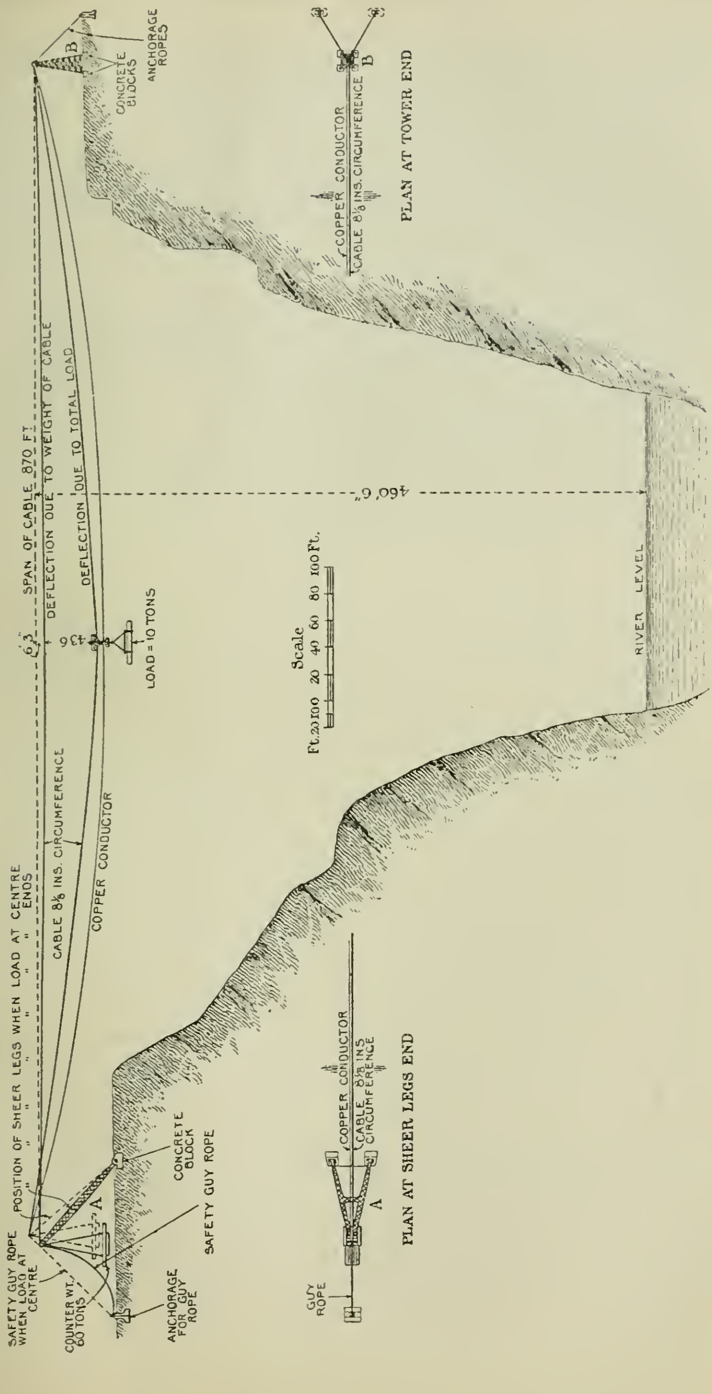

SAFETY GUY ROPE WHEN LOAD AT CENTRE
POSITION OF SHEER LEGS WHEN LOAD AT CENTRE
" " " " " ENDS
COUNTER WT. 60 TONS
ANCHORAGE FOR GUY ROPE
SAFETY GUY ROPE
CONCRETE BLOCK
A
CABLE 8⅛ INS. CIRCUMFERENCE
COPPER CONDUCTOR
SPAN OF CABLE 870 FT.
6'3"
13'6"
DEFLECTION DUE TO WEIGHT OF CABLE
DEFLECTION DUE TO TOTAL LOAD
LOAD = 10 TONS
460'6"
RIVER LEVEL
CONCRETE BLOCKS
ANCHORAGE ROPES
B
Scale
Ft. 20 10 0 20 40 60 80 100 Ft.
GUY ROPE
COPPER CONDUCTOR
CABLE 8⅛ INS CIRCUMFERENCE
PLAN AT SHEER LEGS END
COPPER CONDUCTOR
CABLE 8⅛ INS. CIRCUMFERENCE
PLAN AT TOWER END

FIG. 1.

travelling empty or loaded. The driver's seat is placed so as to be convenient for manipulating the starting switches, resistances, and all the working levers for the rapid working of the machine.

The drums for the lifting gear may be worked independently of each other, and this is essential for the working of tipping buckets.

The speed of hoisting 10 tons is at the rate of 15 ft. per minute, 5 tons at 20 ft. per minute, and 3 tons at 30 ft. per minute. The rate of travelling with 10 tons is 300 ft. per minute, with light loads 450 ft. per minute, and when travelling down the rope to the centre of gravity, without current, 600 ft. per minute.

Great care was taken in the design to reduce the weights to a minimum, and the travelling part of the conveyor weighs 5 tons only.

The working of the machine has proved a complete success, enabling the contractors not only to complete the bridge well within the stipulated time, but to convey thousands of tons of material to the north bank, so that on the opening of the bridge in September last many miles of railway on the other side were completely equipped. The machine was subjected to the most severe tests, and on several occasions carried across a load of 14 tons.

NEWCASTLE LOCAL SECTION.

THE DISTRIBUTION OF MAGNETIC INDUCTION AND HYSTERESIS LOSS IN ARMATURES.

By Dr. W. M. THORNTON, M.Eng., Member.

(*Paper read February 26, 1906.*)

§ 1. BY DIRECT EXPERIMENT.
§ 2. ILLUSTRATION BY STREAM-LINE METHOD.
§ 3. ANALYSIS OF RESULTS.
§ 4. HYSTERESIS LOSS IN TEETH AND CORE.

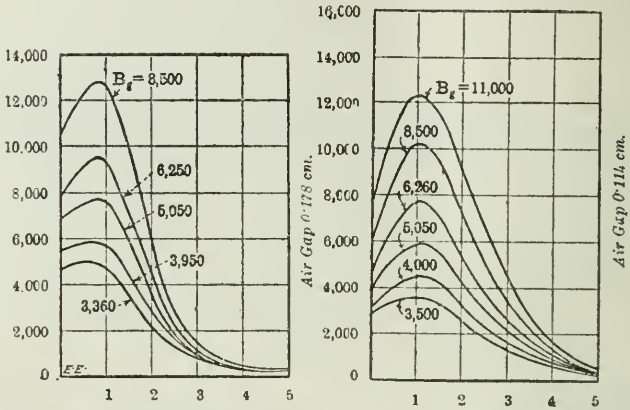
§ 1. The study of magnetic distribution in armatures and poles is important for several reasons. The source and incidence of copper loss is now very well known, but this cannot be said with equal truth of the iron loss, whether it occurs by eddy currents or hysteresis. The success or failure of commutation depends on the induction in the teeth and outer layers of the core, hysteresis and eddy-currênt losses depend equally upon the distribution in the deeper parts. Economy of material and reduction of weight require that the radial depth of the core should be as small as possible, whilst, on the other hand, if it is made too small the full magnetism cannot enter, and the leakage coefficient increases. The factors in the problem are the proportions and permeabilities of core, teeth, and poles, the ratio of peripheral pole-face to pole-pitch, the length of the air-gap, and the flux density in it. So many variables make any attempt at direct calculation of distribution of little value, but experimental investigation is aided by the fact that magnetic laws are precisely the same in a model of small dimensions as in a large machine, and, in the second place, that it is only necessary to observe the distribution within one V-shaped sector included between two pole centre lines.

The result of a preliminary examination of the simplest case of a solid smooth-core armature may be summarised as follows :* (1) The flux densities through a section of the core midway between the poles are in no case uniform, reaching a maximum at a short distance within and falling both towards the centre and circumference, as shown in Figs. 1 and 2 ; (2) the internal distribution is practically the same with long and short air-gaps, though the leakage varies ; (3) the ratio of the

* *Vide* the *Electrician*, August 26, 1904.

maximum density in the core to that in the gap is greatest when the pole-pitch is small ; (4) the variation of magnetisation in passing from one pole to the next is widely different at different depths, so that hysteresis and eddy-current losses are still more unevenly distributed.

The present paper contains an examination of the cases of toothed cores, hollow and solid, by the use of search coils wound in small holes



FIGS. 1 AND 2.—Distribution of Flux Density in Smooth Solid Cores.

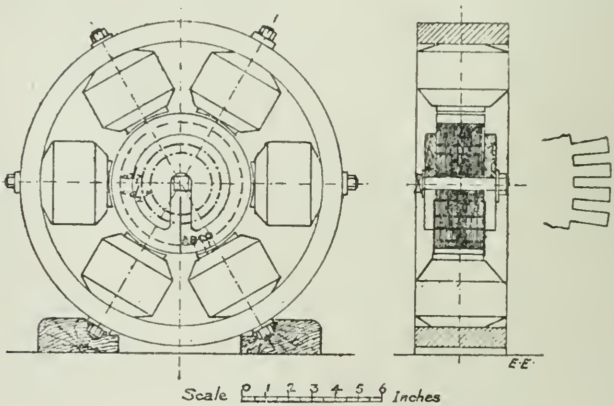


FIG. 3.—Experimental Magnetic Circuit.

drilled through the core parallel to the shaft. When the magnetising circuit is made or broken, the inductive change through each of these in turn is observed by means of a ballistic galvanometer. To avoid the disturbing effect of residual magnetism, a powerful alternating current is passed through the field winding before each reading is taken. The experimental arrangement and the results obtained are shown in Figs. 3, 4, 5, and 6. The solid core was examined first and the radial depth then reduced by boring out the central portions.

The most distinctive feature of these curves, when compared with Figs. 1 and 2, is that the flux density in almost every case decreases from the bottom of the teeth inwards. The exceptions are the curves of Fig. 4, where the core is solid, in which case at the lowest inductions the fall towards the periphery characteristic of the smooth-core curves is again apparent. The reason for this droop is that the leakage from the pole-tips is less at the lower densities, and the lines which do enter the teeth from the leakage fringe pass in nearly straight lines under the

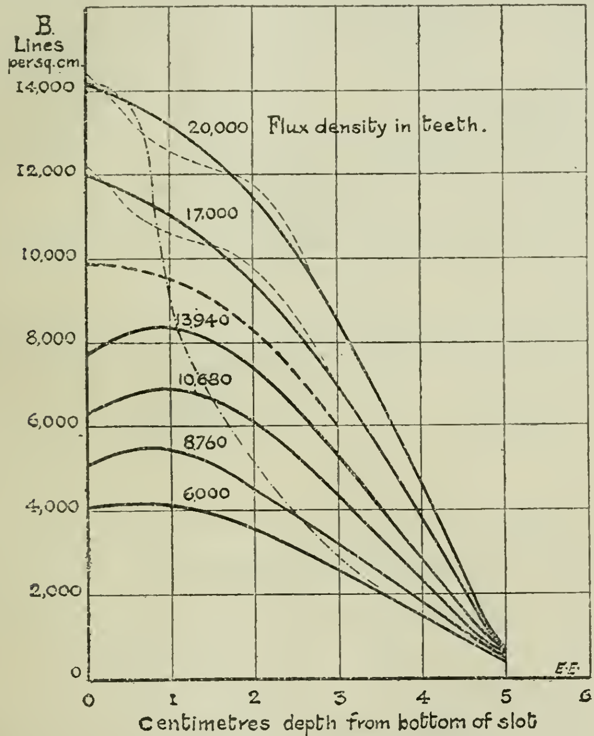


FIG. 4.—Densities in Toothed Solid Core.

teeth across to the next pole, as shown in the photographs Figs. 18 to 23. In machines with a larger number of poles this will not be so marked.

The next point, which is more readily seen by placing together the curves of Figs. 4, 5, and 6, which correspond to the same gap density, is that as the radial depth is reduced the flux densities in the deeper parts are increased relatively to those at the outer. In no case, however, even with the most shallow cores and at low flux densities, does the inner density equal the outer, the nearest value being 0·7 of the maximum for the lowest curve in Fig. 6.

All these curves, it will be noted, give the distribution across a radial section midway between the poles. If, however, the test is repeated with the plane of the armature search coils rotated to positions B, C, D (Fig. 3), the curves not only are steeper near the teeth, but bent upwards at the inner boundary also, as shown in Figs. 7, 8, and 9. So that in these cases the density is least at a distance of about half the depth from the bottom of the teeth. The immediate consequence of making the core too shallow is to reduce the area and increase the reluctance. The increase of leakage between the poles is well shown in the photographs of interpolar induction which follow.

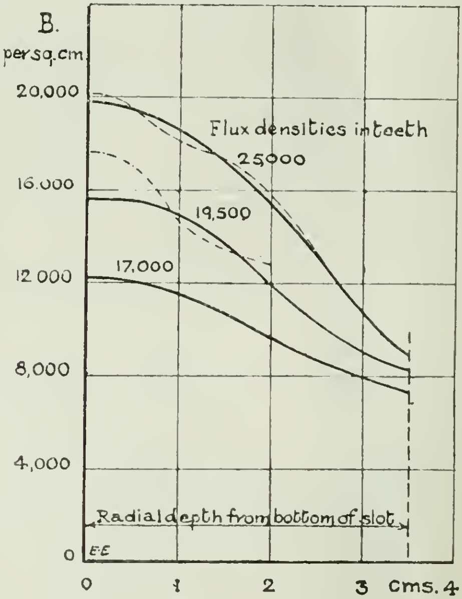


FIG. 5.—Densities in Toothed Hollow Core.

§ 2. These were taken by Professor Hele-Shaw's method of observing stream lines in viscous liquids, which has been fully described in a paper before the Institution.* The authors confined their investigation to the teeth under the poles, so that the sharp bending of the lines on leaving the roots of the teeth and their refraction across slots and teeth were not brought out. The greater part of the magnetism passes through the armature by way of the air-gaps. The magnetism which enters at one pole remains in the plate, except those plates near the ends, though varying in density from point to point, until it leaves at the other pole. The problem of flux distribution in armatures is, therefore, one of two-dimensional flow, though the

* Hele-Shaw, Hay, and Powell, "Magnetic Flux Distribution," *Journal of the Institution of Electrical Engineers*, vol. 34, pp. 21–37, January, 1905.

permeability of the iron is in three dimensions. When a liquid film is so thin that the flow is controlled entirely by viscosity, Hele-Shaw and Hay have shown that the velocity of flow between plates is inversely

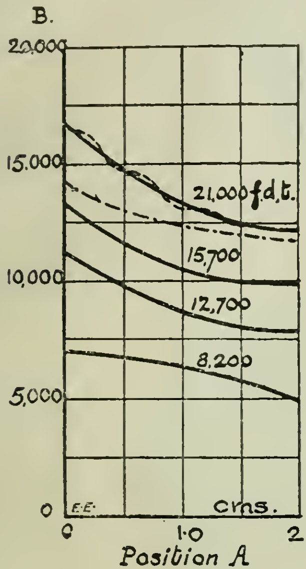


FIG. 6.

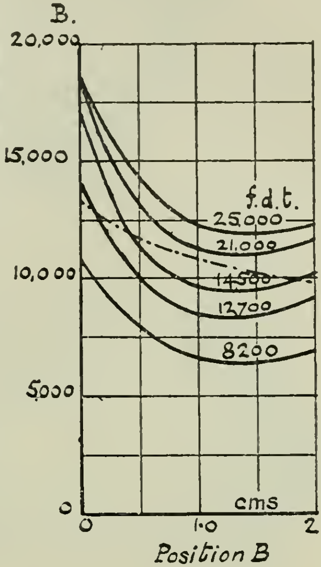


FIG. 7.

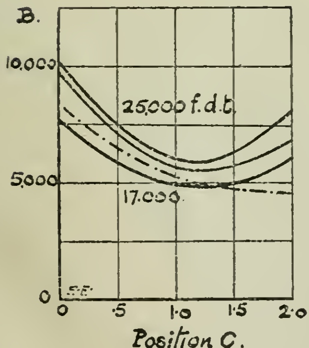


FIG. 8.

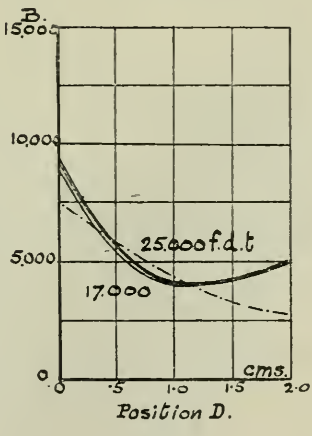


FIG. 9.

proportional to the cube of the thickness of the liquid layer. Under the conditions of the experiment permeability is inversely proportional to the velocity of flow, for Heaviside has shown that in the hydrodynamic analogy velocity of flow is equivalent to H, the slope of magnetic

potential; but if, as in a parallel channel, the number of lines per centimetre width is constant, μ is inversely proportional to H. In order, therefore, to compare the curves obtained by direct experiment on the iron with the stream lines, one has only to measure the number of the latter crossing a line of unit length at right angles to them and at different depths in the section. These correspond to the readings of the ballistic galvanometer in the direct experiment.

To illustrate the nature of the distribution the stream-line method is very helpful, though it is impossible to represent the automatic change of permeability from point to point. It is, however, possible, as will be shown by the photographs, to work with three or more different permeabilities in the same slide, as, for example, in poles, air-gap, teeth, and armature core. To do this, a special narrow tool was made and clamped to the planing machine used in preparing the wax slides. Taking care to have its cutting edge quite straight and parallel to the face plate, large and small surfaces could be planed which did not afterwards distort the lines of flow in any way.

The first set of photographs (Figs. 10 to 15) represent the distribution in smooth cores, and so correspond to the curves of Figs. 1 and 2. They explain themselves in their general features. The well-known effect of large air-gaps increasing leakage is illustrated by Figs. 11 and 15. The same effect is produced by making the poles of lower permeability, or, in other words, increasing the density in them. This is shown by Fig. 14, in which, though the core is solid, the leakage is greater than in Fig. 15 with poles worked at higher permeability. It is often possible by this hydrodynamical method to push a case to its limiting value, as, for example, in Figs. 16 and 17, where the air-gap has been entirely removed, and there is no joint between pole and armature. In this case the influence of low permeability in the poles upon the leakage fringe is clear. Figs. 18 to 23 give the distribution in slotted cores. In order to represent actual conditions as closely as possible, some slides were made with teeth and poles of different thicknesses imitating the sequence of permeabilities met by the flux in crossing the gap. The refraction of the lines in the fringe in their attempt to reach the core, and the nature of the interpolar induction as compared with that for smooth cores, are of most interest. The permeabilities in all the cases of smooth and slotted cores being fixed, very little change is made by an alteration of the pressure on the slide or the velocity of flow. The hydrodynamical method, therefore, corresponds to the cases where the induction density is so high that there is saturation in the iron—that is, to the highest curves in Figs. 4, 5, and 6.

§ 3. The photographs can be analysed by measuring the lines per centimetre width in the same way as one measures the lines per square centimetre with the ballistic galvanometer, and can also be expressed in electromagnetic units. Let B_1 equal the number of lines measured at right angles to their direction of flow. Whatever the value of B_1 we may let it represent any number of magnetic lines we please. For example, 30 lines per centimetre in the photographs may be assumed

130 a.

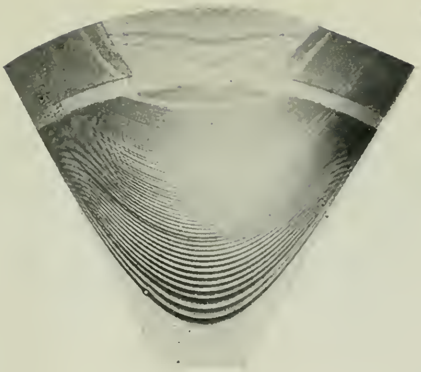


FIG. 10.

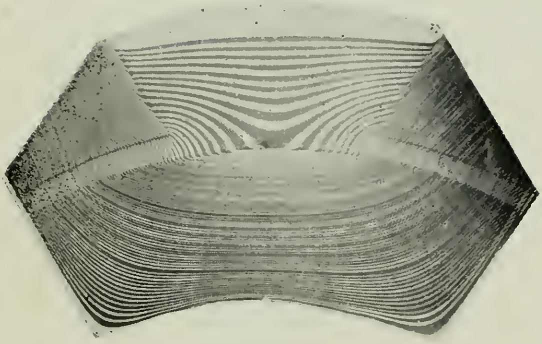


FIG. 11.

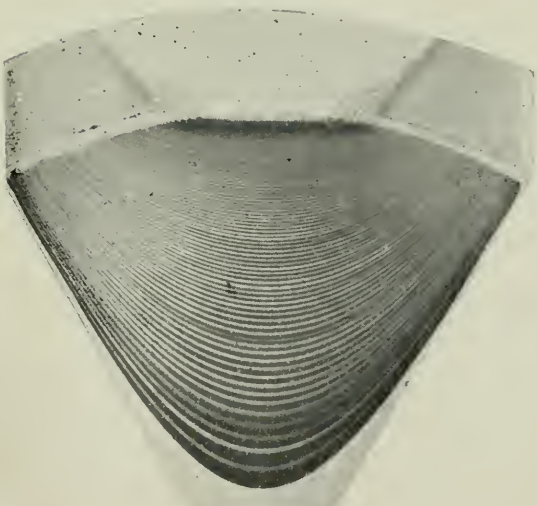


FIG. 12.
Stream Lines of Magnetic Induction in Smooth Cores.

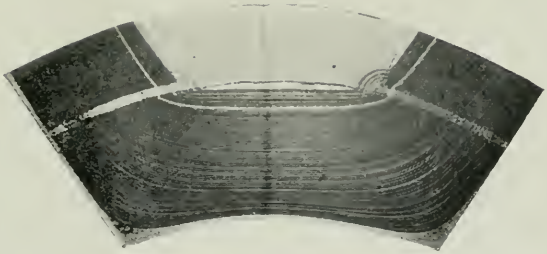


FIG. 13.

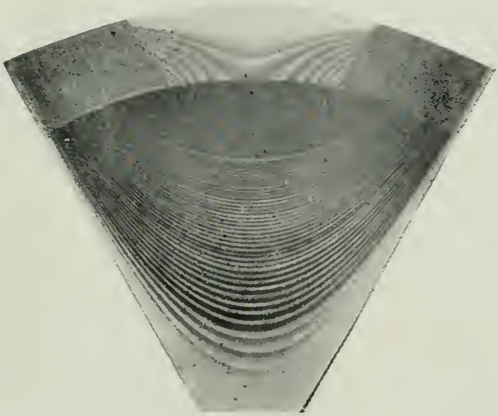


FIG. 14.

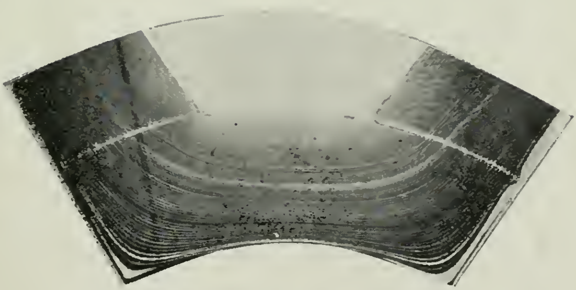
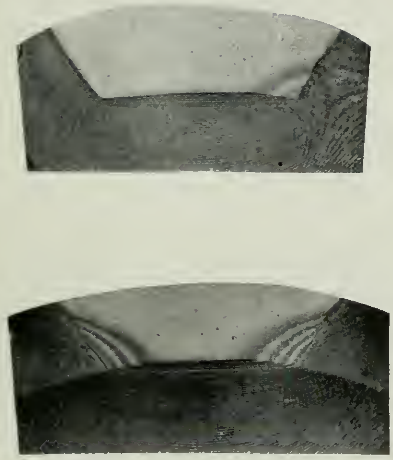


FIG. 15.

Stream Lines of Magnetic Induction in Smooth Cores.



FIGS. 16 AND 17.—Influence of High Density in Poles upon Leakage.

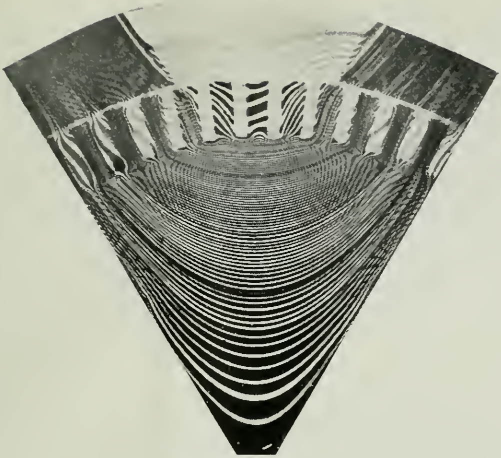


Fig. 18.

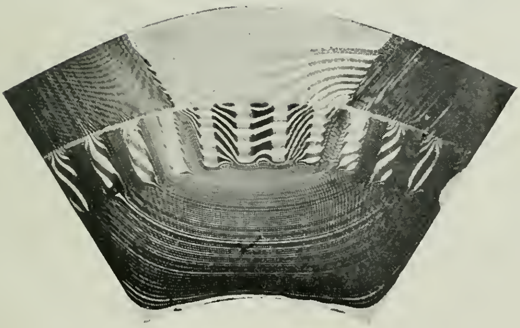


Fig. 19.

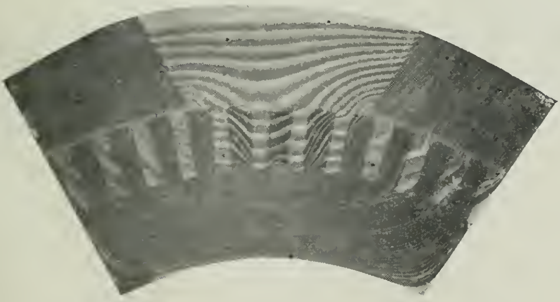


Fig. 20.

Lines of Magnetic Induction in Toothed Cores.

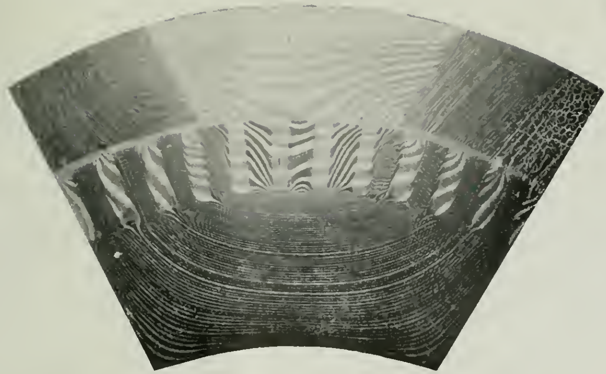


FIG. 21.

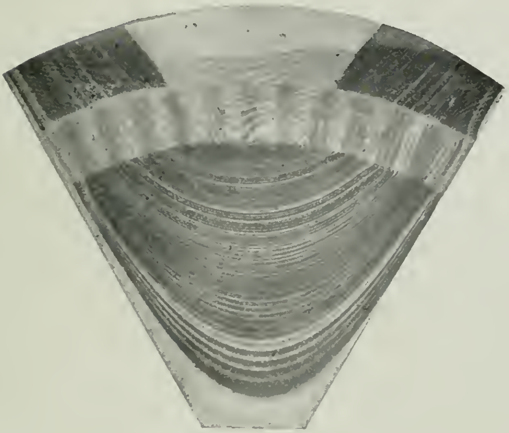


FIG. 22.

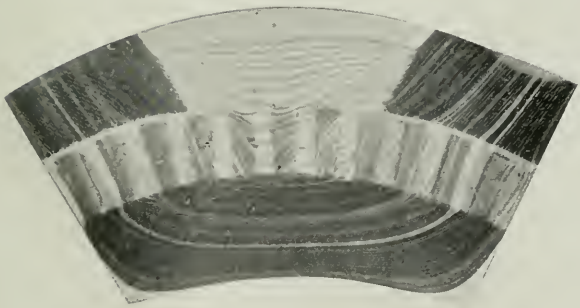


FIG. 23.

Lines of Magnetic Induction in Toothed Cores.

130 f

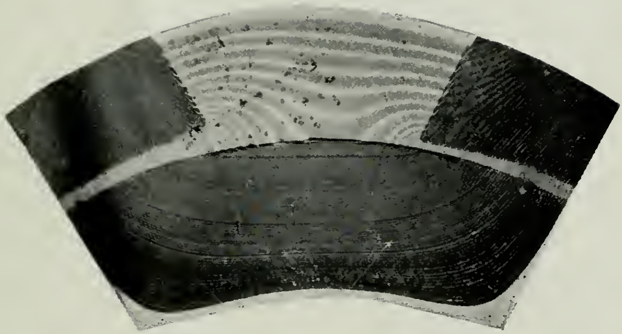


FIG. 24.—Imitation of Armature Reaction.

to represent 10,000 lines or tubes of force in the air-gap where μ is unity. The corresponding value of H is then 10,000 absolute electromagnetic units. If, now, at another part of the slide the lines are 48 to the centimetre, the induction density there is 480,000/30, or 16,000. The value of H depends upon that of μ. Let this be made 100, by adjustment of the thickness of the channels in the slide, then H is 16,000/100, or 160 absolute units. The distribution of magnetic potential could, therefore, be drawn, and would be a first approximation to the actual case, differing from it because the permeability in iron cannot be fully imitated. The chain-dotted curves of Figs. 4 to 9 are obtained in this way from the stream-line photographs. In the solid core case (Fig. 4) the agreement is not very good, but the others are better. The difference is no doubt the effect of the constant and comparatively low permeability of the slide. In a solid core, for example, there is a high density and low permeability—about 100—at the root of each tooth, but a very low density and a permeability from 1,000 upwards towards the centre. Such a range as this cannot be imitated, and if high numerical accuracy is required in working with the stream lines, cases where the permeability changes from point to point must be avoided.

There is an interesting feature which appears in the curves, whether from the direct experiment or from the photographs of stream lines. In drawing the highest curves of Figs. 4 and 5 it was noticed that they had a wavy appearance. The meaning of this was not clear at the time, but when the stream-line curves came to be drawn it was found that the same feature appeared, and it was then traced to the action of the teeth. It may even be seen without measurement that in some of the curves (for example, Figs. 18 and 19) the lines which pass through the teeth into the core are denser than those which are in line with the slot. This difference of density may be followed through the core to the opposite pole. The induction, in fact, at high densities lies in streaks in the part of the coil below the teeth. This might be expected to be more marked in alternators where the teeth and slots per pole are fewer, but it only occurs at high induction densities. The fact that it does so is an indirect proof of the statement previously made, that the stream-line curves correspond to cases of high densities in the iron.

The success of commutating machines depends largely upon the relative values of field and armature ampere-turns. An attempt was made to compare their influence on the core flux by forming a winding in the slots of the model. Beyond a slight displacement of the magnetic centre line of the pole the internal distribution is little changed. The difference between the readings at positions A, B, and D, when the field and armature currents were broken at the same instant, and when the field alone was broken, the armature being then on open circuit, was on an average less than 5 per cent. The influence on the density in the teeth would, no doubt, be greater, but this unfortunately could not be tried. From experiments made with the oscillograph on pole-flux distribution in a 5-k.w. 6-pole drum machine with 5,000 lines per square centimetre in the gap, it may be said that the average

density in the teeth under the pole-tips does not appear to change by more than 20 per cent. from no load to full load. Under the centre of the pole they are unaffected. Fig. 24 shows the general nature of the change in a smooth-core armature, the influence of armature reaction upon the air-gap density being the same as that of varying the reluctance of the gap. The centre line of the interpolar induction has moved in the wrong direction. In practice this is no doubt compensated by the change of density in the poles, but it indicates that movement of the brushes is more a question of finding a reversing field than of following the neutral line.

It was shown at the conclusion of the paper quoted, that with smooth cores when the ratio of radial depth to radius is half the number of poles, the flux density at the inner boundary is about half

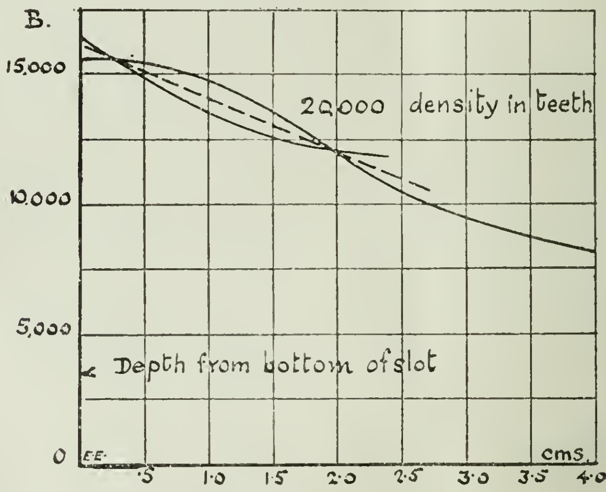


FIG. 25.—Average Fall of Density in Core.

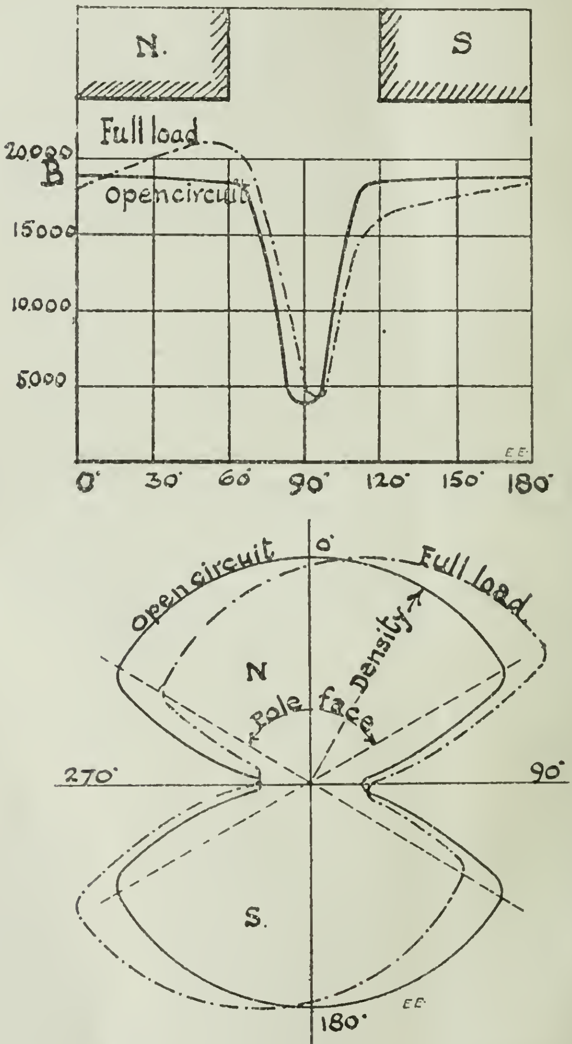
the maximum value in the core, at a section midway between the poles. To compare the case of slotted cores, we may take Figs. 5 and 6 as representing working conditions. The ratio of radial depth to radius in Fig. 5 is 0·46, and in Fig. 6, 0·264. The former is, therefore, too deep and the latter too shallow for the above rule. The mean of these distributions when there is a flux density of 20,000 in the teeth is shown in Fig. 25, and is practically a straight line from 11,000 lines per square centimetre inside to 16,000 at the bottom of the teeth, a ratio of minimum to maximum of 0·687. Thus, if, in designing a machine, the induction in the core is assumed to be uniform at 13,500 lines per square centimetre, the departure from this would be 18 per cent. above and below, so that the mean density is 82 per cent. of the maximum. The flux density just below the teeth in Fig. 5 is, on an average, 0·75 of that in the teeth measured at right angles to the lines under a slot.

That in Fig. 6, with a shallow core, is 0·85 of the tooth density. The mean of these would very probably correspond to most working cases. In order, then, to find the distribution in a slotted core at a position midway between the pole-tips, or on the neutral magnetic line if the machine is on load, take 0·8 of the mean density in the teeth and 0·82 of this, the result, or 65 per cent. of the teeth density, will be the mean density in the core. With ratios of radial depth to radius greater than 0·33 the mean value is less than this, and in general varies inversely with the ratio.

§ 4. *Calculation of Hysteresis Loss in Teeth from Curves.*—The loss by hysteresis in an armature may be dealt with in two parts—teeth and core. So long as the number of lines in the tooth does not change, as, for example, in passing under a pole, there is no dissipation of energy. Approaching the pole-tip the lines become oblique, and midway between the poles horizontal, though the density never drops to zero. There is, therefore, a rotating magnetisation in the teeth which is at the same time fluctuating between limits which can be found from the photographs. Thus in Fig. 23 there are thirteen lines entering a tooth vertically under the pole and eight horizontally when the tooth is midway between the poles. There have been many calculations of this loss based on assumptions as to the manner in which the density changes in the teeth, but all assume an alternating flux. The fact that, as shown by the photographs, it is partly rotating is likely to reduce the estimate of hysteresis loss in teeth, which, though too small to affect efficiency to any marked extent, does influence the temperature of the insulation of the armature conductors. The loss in any case cannot follow Steinmetz's law as generally assumed. Consider the variation of density in the teeth passing from pole to pole. Without having regard to sign, it can be represented by Fig. 26, or more closely by Fig. 27. Under the pole the density is constant in magnitude and direction, between the poles it is changing rapidly and rotating. In the hysteresis loop obtained by rising and falling magnetisation the dissipation of energy is very greatly increased by the molecular movement at reversal, but when, as in the case considered, the density never passes through zero, one must take as a basis the loss due to a rotating field. Hawkins and Wallis in "The Dynamo," Fig. 133, p. 286, give a curve of loss of energy by rotating and alternating magnetisation. The ratio of maximum to minimum density in the teeth is found from Figs. 18 to 23 to be about 4·5. Assuming, then, a maximum of 18,000 and a minimum of 4,000 with a rate of change as in Fig. 26, the mean dissipation coefficient is 0·00105 joule per cubic centimetre per pair of poles. This is found by taking Fig. 26 and erecting ordinates of the rate of heating at each point as in Fig. 28; the mean height of the curve gives the mean dissipation coefficient in the teeth. If, on the other hand, the teeth are considered to have alternating magnetisation only, the rate of dissipation is increased to 0·0022 over the given range of density. The influence of the rotation is then to very much reduce the rate of heating in the teeth so far as this is caused by hysteresis.

When the machine is on load, the distribution of the lines in the

gap being somewhat changed, there is also a variation of density in the teeth from point to point under the pole, though there is no rotation. The effect is to shear the distribution over, as in Figs. 26



FIGS. 26 AND 27.—Distribution of Density in Teeth between Poles.

and 27. For all practical purposes, the hysteresis loss in the teeth may be considered to be unaffected by the change, as shown in Fig. 28. The fact that the loss by rotating magnetisation decreases after reaching a maximum contributes to this.

In the foregoing the change of density from top to bottom of the tooth has not been considered as affecting hysteresis loss. On approaching and leaving the pole-tips the distribution of flux becomes

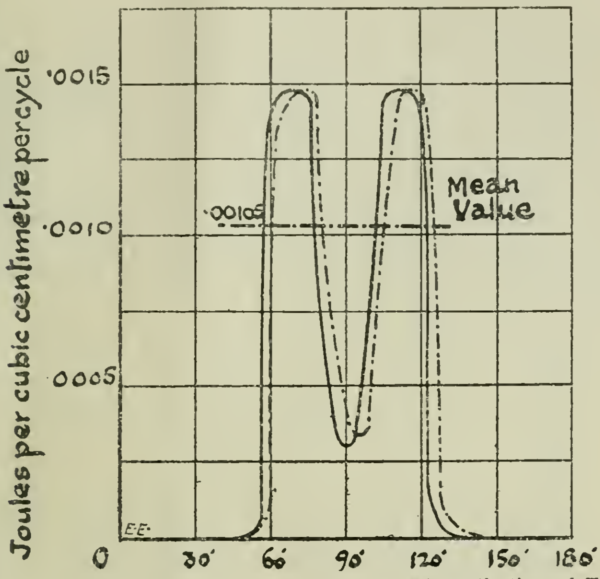


FIG. 28.—Variation of Heating with Rotating Magnetisation of Teeth.

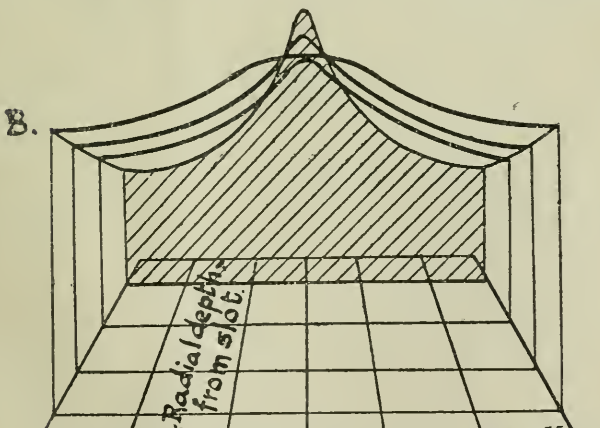


FIG. 29.—Distribution of Density in Core below Teeth.

more uniform in the teeth, and since the molecular movement is confined to the interpolar space, this change of density will not make any marked difference.

The hysteresis loss in the parts of the core below the teeth also depends on the manner in which the cycle of magnetisation is carried through at each point. There is, however, much less variation than in the teeth. Fig. 29 shows how the density *measured always at right angles to the lines* changes in passing between two pole centre lines. It is not in perspective, but the circular arcs are projected into straight lines. The lines of force were measured on Fig. 20. Direct experiments on the model do not give much clue to the true density, but only that in a plane perpendicular to the circumference. In order to find the mean hysteresis loss from this, the dissipation coefficient for rotating magnetisation is found, as in Fig. 30, for each ordinate at successive depths in the core. The mean height of each curve gives the average heating per cubic centimetre at any radius, but the outer layers have more weight in estimating the mean loss for the whole core by reason of the contraction of the section towards the centre. The mean height of

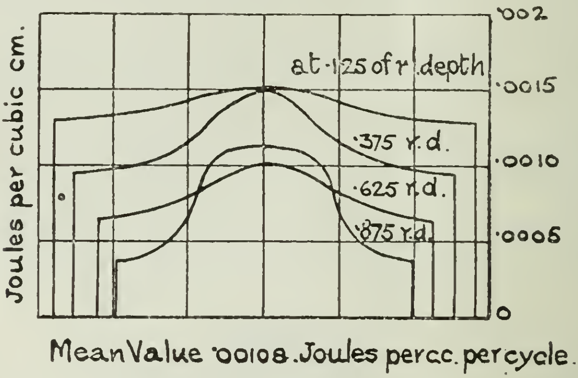


FIG. 30.—Variation of Rate of Heating in Core below Teeth.

each curve was, therefore, multiplied by its base, and the average of these products divided by the base at the middle depth, this giving the mean height for the whole core. For the case considered this works out to be 0·00108 joule per cubic centimetre per cycle—*i.e.*, per pair of poles.

The stream-line method being at best an approximation, results found in this way are also approximate, but it is difficult to see how else to proceed. What is usually done in practice is to take the mean flux density for the core and to find the corresponding dissipation coefficient. In the above case, when Fig. 25 is taken as a basis for attaching numerical values to the stream lines, the mean for the whole core is about 13,000 lines per square centimetre, and the loss by rotating magnetisation at this density is 0·0013 joule per cubic centimetre per cycle. The hysteresis loss in the core is, therefore, about 20 per cent. less than it would be if the density were uniform throughout.

The work was originally undertaken to obtain material by which the ratio of hysteresis to eddy-current loss in armatures could be found.

It was felt that this could not be done with any confidence until the induction density at every part of the core throughout the cycle was known. The experiments described, though leaving many questions unanswered, as, for example, the influence of closing the slots, at least serve to indicate the nature and magnitude of the results to be expected in machines on a large scale. The eddy-current loss has not yet been fully worked out.

The results in the paper may be summarised as follows: The magnetisation of the teeth in slotted armatures is not alternating, but rotating, and at the same time fluctuating; that of the core is rotating, but by reason of the distribution of density in the core not being uniform, it is unevenly distributed, being greatest at the outer parts below the teeth. The ratio of the mean dissipation coefficient to that corresponding to the mean density is about 0·8. The coefficient for the teeth alone is about 0·00105 joule per cubic centimetre per cycle; that for the core 0·00108. The low value for the teeth is caused by the drop in density between the poles and by the fact that it is rotating.

In conclusion, I wish to thank Mr. O. J. Williams and Messrs. G. H. and C. Wilson for much help in taking the readings and the photographs.

DISCUSSION.

Mr. G. Stoney: Dr. Thornton is to be congratulated on his most interesting paper. I think that the confirmation of the magnetic densities as found by the model core by the stream line method is most interesting, and that by no other method can the way of the lines of force, not only in the core and in the teeth, but also in the leakage field, be so well shown, so as to enable the mind to realise how they actually go. In his model core Dr. Thornton has only one line of holes, which give the magnetic densities at right angles to the radius. By having a second set close to these the radial densities can also be obtained, and thus the real direction and amount of the lines of force can be determined, as in the stream line method. I believe this was done some years ago by some American experimenters. I think practical dynamo designers will hardly agree with Dr. Thornton that the hysteresis loss in cores is less than that given by Steinmetz's formula. The whole question of hysteresis loss in complicated cycles of magnetisation is a most difficult one, and one where there is much need of further experiment. Some years ago I made some experiments* on this subject. Want of time prevented their being carried to a conclusion, but what I did seemed to show losses much larger than would be expected from Steinmetz's law. Mr. Stoney.

Mr. C. Turnbull: I am of opinion that the system of drilling holes in iron will alter the magnetic flux near to the holes, and thus vitiate the result. As regards Mr. Stoney's experience that hysteresis losses in actual practice are so much greater than the calculated losses, I suggest that it is possible that the eddy-current losses in the plates are really greater than estimated. The plates are all connected at the Mr. Turnbull.

* *Institution of Electrical Engineers Journal*, vol. 33, p. 560.

Mr. Turnbull.

spindle, and the separation at the outer edge is not always good, and may be even worse when the armature is hot.

Mr. Carter.

Mr. T. CARTER: The value of Fig. 24 seems to be lessened because the shape of the pole-pieces in the model does not correspond to what is actually used in practice, one having an air-gap widening towards the edge while the other becomes narrower. This may tend to accentuate the movement of the stream line neutral point in a backward direction more than would actually be the case. As regards hysteresis, since the iron losses are so difficult to calculate from theoretical grounds only, I hoped that, as Dr. Thornton has cleared the ground, some work may be done as a sequel which will deal with the losses as actually found in practice, and will attempt to find some empirical equation which will give good results without the necessity of working out each part theoretically. If something could be found which will always give results within 10 per cent. even of the true value, it would be a great boon to designers.

Mr. Brown.

Mr. E. EUGENE BROWN: With reference to getting the varying values of the induction with a model, I do not think that can be applied to the case of a rotating armature, as when the armature is rotated, the fluctuations due to the teeth make a great difference to the distribution of the induction. In the case of a smooth core with a large gap some important, though not very complete, information may be gained. The two cases of a rotating core and a stationary transformer give very different results. It is seldom that one gets the hysteresis losses to come up to the calculation when tested, but it is always difficult to separate them from the eddy-current losses. One may use Steinmetz's law of the 1·6 power, which is perhaps satisfactory for the core of the armature, within the limits of the induction in practice, but it is quite different in the teeth, where the induction is so high and so fluctuating. Regarding the stream lines, I do not think they give information of what actually happens. As Dr. Thornton said, they are made to fit the case, as one cannot produce the actual variation of conditions in the experiment. Fig. 24 is a case where the desired result is obtained by altering the shape of the pole-pieces. I think that the model used by Dr. Thornton is too small, and that a large one, made so that the holes are practically insignificant, would be better.

Dr. Thornton.

Dr. THORNTON (*in reply*): The stream line method of investigation is suggestive, but it is accurate only in simple cases. It has been shown to be mathematically accurate by the authors of the method, Professors Hele-Shaw and Alfred Hay, in a paper read before the Royal Society. The chief interest of the new photographs lies in the form of the inter-polar field, the permeability of which is of course constant, and that across the teeth, from pole to pole. The direct investigation on the model is more accurate but much more laborious. Mr. Stoney suggested another set of holes at right angles to the first, and records from these would have been very useful in comparing the stream line with the actual flux distribution. It would be worth while taking a fresh set of observations with these additional coils. With regard to hysteresis loss, my point is that it is impossible to find the

Dr. Thornton.

hysteresis and eddy-current loss in the armature core by any running tests, because the energy for the eddy-current losses in the pole faces or poles has to be supplied through the armature and appears at first sight to be dissipated in the armature. The fact that the eddy-current loss varies at somewhat less than the square of the speed, proves beyond doubt that there must be some loss in the poles, for eddy-current loss in solid masses follows a lower index than the square, whilst in thin plates of the dimensions used in armatures it is as the square. I think that the statical method, where the influence of frequency is eliminated, gives a more reliable basis to start from in comparing eddy-current and hysteresis loss under known conditions. In reply to Mr. Brown, the movement of the lines in the core caused by the change of position of the teeth is slight in itself, and does not, I think, affect the losses perceptibly, unless there are few teeth per pole. The model was made to these dimensions after careful consideration of the distortive influence of the holes, which are 0·09 in. diameter. I believe that their influence is inappreciable. In reply to Mr. Carter, the shaped air-gap in the slides would probably cause a change in the total number of lines entering the core from the pole tips, but it would not, I think, affect the form of their distribution in the space between the poles or the position of the neutral line. Professor Kapp long ago showed experimentally that a reversing field is necessary for successful commutation. I suggest that machines with fixed brushes are possible not wholly because of the resistance of the brushes, but from the fact that, whereas the brushes of a generator have usually to be moved forward in order to find a reversing field, by making the armature ampere-turns a suitable proportion of those of the field, the blowing out of the lines can be made to provide automatically the required reversing field without movement of the brushes. In conclusion, I wish to say that the experiments and deductions are intended to be suggestive rather than to find working formulæ. In so far as the exact nature of the magnetic movement within machines is unknown, it is difficult to obtain working formulæ reliable over much range. Every designer has his own coefficients for each type of machine to fit the results on test, and no isolated set of experiments can do more than suggest a fresh interpretation of them. I find in *Science Abstracts* for 1900 (Abstract 589) a note of the paper by Professor Goldsborough, mentioned by Mr. Stoney. He used a V-shaped slice of the armature core with holes drilled through it at various places. I have used one set of holes and a complete armature, rotating the holes to different positions in succession.

GLASGOW LOCAL SECTION.

THE INTERNAL ENERGY OF ELEMENTS.

By F. Soddy, M.A.

(*Paper read March* 13, 1906.)

It is recognised that the energy possessed by any system cannot be known unless it is possible to change the state of the system. On the other hand, where it is possible to change the state of the system, the *difference* in the energy-contents of the initial and final states can be found, but not the total energy-content of either state. In the transformation which matter undergoes in ordinary chemical changes, the change of energy accompanying the change of state can readily be found, but not the total energy possessed by either state. Thus when carbon burns in oxygen to give carbon dioxide, 97,000 calories are evolved for every 12 grams by weight of carbon and 32 grams by weight of oxygen combining. We know practically nothing of the total energy contained either in carbon or oxygen or carbon dioxide. All that can be said is that if the sum of the energies in the weights of carbon and oxygen referred to is represented by x calories, the energy of the carbon dioxide is represented by $x - 97{,}000$ calories.

Since all matter can be regarded as built up out of component elements, it is usual to regard the latter as the starting-points from which the energy-content of all matter is reckoned, and, as a convention, to give all the elements zero energy-content. This, of course, as the above example sufficiently shows, does not imply that the elements are devoid of energy. By a similar convention the earth is regarded as possessing zero potential.

None of the material changes dealt with in chemistry are very profound. Every one, nowadays, would regard the carbon and the oxygen as still existing in the carbon dioxide, for by supplying the energy which was evolved in their union we can easily get from the compound the same elements in the same amount as originally. Now if the elements had utterly disappeared as such when the compound was formed, and did not still exist practically intact in the compound, there would be no reason why on decomposing the compound we should get back carbon and oxygen; we might expect to get back any other elements, say hydrogen and nitrogen. For this reason chemistry affords no indication of the internal energy of the elements. The

latter cannot be fundamentally changed or converted the one into the other. Since in all chemical changes they remain essentially intact, their internal energy must remain always constant and therefore latent and unknowable.

Yet from the earliest times the idea of more fundamental changes has held the imagination of the investigator. It is notorious that no process has succeeded in artificially transmuting one kind of element into another, although till now it has not been possible to give any very clear reason for this impossibility. We see, at least, quite clearly that it is only by studying some such process as transmutation that we can ever hope to find out anything at all of the internal energy of the elements, and of the total store of energy resident in matter.

The discovery of the natural radio-activity of certain elements—first for the element uranium by M. Henri Becquerel in 1896 and later for the element thorium—threatened to undermine the foundations of physical science, for the property of radio-activity involves a spontaneous and continuous evolution of energy. The amount evolved depends only on the quantity of the radio-active element, and is entirely independent of all conditions or of the particular form or compound in which the element is combined. This steady evolution of energy goes on in the minerals in which the element exists in nature no less than after they have been extracted from them and obtained in the pure state, and the evolution is continuous from year to year, and from all we know from one geological epoch to another. It is not affected by temperature, for the experiment has been tried both at the highest and the lowest temperature it is possible to attain, and no process or agency with which we are acquainted in the slightest degree arrests or accelerates the radio-activity.

The radio-elements are without exception those which possess the heavies atoms, and therefore presumably are those possessing the most complex structure known.

The quantity of energy evolved is extremely small in the case of the common and older-known elements uranium and thorium, but it is manifested in a way which lends itself very readily to detection and investigation. The elements in question possess the power of emitting new kinds of radiation with characteristic properties, and among the most important of these is the power possessed by the rays of ionising the air or other gases through which they pass. Ordinarily almost perfect insulators, gases in the ionised state are able to conduct minute currents of electricity, and the electricity is transported by the convection of charged ions, the same as in electrolysis. A gold-leaf electroscope which, under ordinary circumstances, retains its charge for days, is discharged almost immediately when the air surrounding the charged system is exposed to the radiations from uranium. If a kind of uranium were found which did not show this property it would be as remarkable a discovery as if a kind of sodium were found which did not give a yellow line in its spectrum. Radio-activity is an intrinsic property of the element, and owes its origin to a process to which we and the forces under our control are external. It is a

property bound up with that inner existence of the element which we have seen survives intact the transformations due to all chemical changes, and against which the efforts alike of the alchemist and the chemist have been directed in vain.

Rutherford found that thorium possesses an even more remarkable property than the emission of rays, and since then the same has been found to be true for radium and actinium, but not for uranium or polonium. Thorium and its compounds give off continually a radio-active "emanation," which is in reality a new kind of gas possessing radio-active properties. These emanations diffuse through the air away from the neighbourhood of the radio-active compound, and can be led through tubes and condensed by extreme cold. Much as a scent may be detected by its smell when only present in infinitesimal quantities, so these emanations can be detected by their radio-activity, that is, by their power of giving out radiations and ionising the air, although their quantity is almost always so extremely small that no other indication of their presence exists.

It has long been known that thorium and radium possess the power of causing any object in their immediate neighbourhood to become temporarily radio-active, and this phenomenon is alluded to as the "induced" or "excited" radio-activity. This Rutherford showed to be due to the emanation. The latter appears to re-deposit as a film upon any solid object it comes in contact with, and this film, although invisible and unweighable, is known, like the emanation itself, by its strong radio-activity. It can be rubbed off with sandpaper or dissolved off with acids, the radio-activity being transferred to the sandpaper or acid solution.

Neither the radio-activity of the emanation, nor that of the induced activity to which it gives rise, is permanent. Each steadily decays with time when left to itself, and the decay follows always a regular geometrical law. Thus the thorium emanation, after it has diffused away from the thorium producing it, loses half its activity in a minute, three-quarters in two minutes, seven-eighths in three minutes, and so on. The radium emanation takes four days for its activity to be reduced to half value. The induced activity of thorium has a period of about eleven hours, and that of radium of about thirty minutes, in which the activity falls to half the initial value.

An exhaustive investigation of the radio-activity of thorium resulted in other discoveries being made, and as a result Rutherford, in conjunction with the author, in 1902, advanced a theory accounting for the phenomenon of radio-activity. On this view radio-activity was regarded as being due to more fundamental changes in matter than had hitherto been known, and in which the elements themselves underwent a species of natural transmutation into other elements. A definite fraction, usually an infinitesimal fraction, of the total number of atoms was regarded as spontaneously exploding or disintegrating in each unit of time; the rays emitted were regarded as being due to the lighter fragments of the original heavy atom expelled like projectiles with great violence and ionising the air molecules in their

path; while the emanations and allied bodies were regarded as the residues of the original atoms left after the expulsion of these radiant particles. These emanations remain in existence on the average a definite short time, 87 seconds in the case of the thorium emanation, and 5·3 days in the case of the radium emanation, and then again suffer disintegration, expelling more radiant particles and changing into the non-volatile films which cause the induced activity. So the disintegration goes on from one stage to another, and the stages can be detected by the radiant particles expelled and the new transition-forms of matter successively produced. In radium at the present time no less than eight such successive disintegrations have been traced. The period of average life of the successive transition-forms varies from years in some cases to a few seconds in others.

The main evidence for this view is that these intermediate types can be separated from the parent element, and concomitant with the steady decay of their activity a fresh crop is reproduced by the parent element. Thus four days after the emanation has been blown out of a bottle containing radium its activity will have fallen to half the initial value, and if in the meantime the bottle has been kept closed it will be found that a fresh crop of the emanation has re-formed in the interval equal to half of the initial amount. In eight days the activity of the separated emanation will have fallen to one-fourth of the initial, and the emanation reproduced will be three-fourths. This process of reproduction of the emanation is taking place continuously, whether that produced is removed or not. In the latter case an equilibrium is soon reached, as much being produced from the radium per second as disappears by further change, and then the quantity present remains constant.

If a phenomenon cannot be explained it may sometimes be safely ignored, and it is safe to say that this would long have been the fate of radio-activity and of any upsetting theory to which it had given rise had the phenomena been known only on the scale and in the degree exhibited by the elements uranium and thorium. But the work of M. and Mme. Curie in their discovery of the element radium, and in the isolation of compounds of the element in a pure state, made the scientific world familiar with an element over a million times as active as uranium and thorium. In this case no delicate electrical test is needed to show the radiations. They produce brilliant luminous effects on fluorescent substances such as the platinocyanide of barium and the mineral willemite (zinc silicate). The energy evolved is so great that it comes within the range of an ordinary thermometer. A pure radium salt maintains itself some degrees above the temperature of its surroundings. The actual amount of heat evolved has been determined by Curie and Laborde, and shown to amount to 100 calories per gram of radium per hour. This is sufficient to raise a weight of water equal to that of the radium from the freezing-point to the boiling-point every hour. In one day the heat evolved, therefore, is greater than from a similar weight of coal and oxygen during combustion. In a year it is nearly four hundred times greater, and yet

at the end of the year the evolution of energy is, so far as exact measurements can show, no less than at the beginning.

In face of experimental facts such as these even the fundamental theories of physical science could not be accepted unquestioned. The idea of atomic disintegration, although no doubt it dispels some scientific prejudices, does not, however, upset a single established principle. The process being due to fundamental changes in the elements themselves, the energy evolved is to be ascribed to the store of internal energy of the elements. This remains, as we have seen in all chemical changes, latent and unknowable, and is now for the first time revealed.

The existence of such a powerfully radio-active element as radium enabled the disintegration theory to be more directly tested than was before possible. So far, nothing has been said as to the ultimate products into which the radio-elements change after the disintegration has gone to completion, and nothing of the nature of the small fragments expelled from the heavy atom in the form of radiant particles. These questions are difficult to settle. Radio-activity is essentially an energy phenomenon, and we know that radiant particles are being expelled on account of the energy they possess. It does not follow that we can decide the chemical problem as to the nature of the particles. A soldier on a battle-field might have quite indisputable evidence that the enemy were firing ball cartridge, without in the least knowing what metal the bullets were made of.

However, from the first it was possible to make a shrewd prediction of the nature of the radiant particles. The evidence pointed unmistakably to the element helium. In the minerals containing the radio-elements, the products of the changes will have accumulated during past ages, and such products may therefore be expected to exist in recognisable quantity in these minerals as the invariable companions of the radio-elements. Helium is found in the radio-active minerals, and only in those minerals, and other evidence indicated that the radiant particles expelled during disintegration were probably atoms of helium. Sir William Ramsay and the author were able to show directly that there is a continuous production of helium from radium in sufficient quantity to be recognisable by the spectroscope, and from other experiments of a similar nature they estimated that probably about one thousandth part of the radium disintegrates (primarily into the emanation and helium) every year. These experiments have been repeatedly confirmed by other investigators.

From one point of view, the phenomena exhibited by radium are no more wonderful than those exhibited by uranium. While radium is a million times more powerful, there is a million times less radium in existence than uranium. We now know from recent experiments that radium is itself a product of uranium, and is in fact a transition-form in the uranium disintegration series, with a period of average life between one thousand and two thousand years. The uranium is a million times less active than radium because it is changing a million times less rapidly, and will therefore last a million times as long. But, as a

consequence, for every gram of radium found in a mineral there must exist at least a ton of uranium. One thousand-millionth part, or one milligram per ton, of the uranium undergoes change yearly, producing nearly one milligram of radium (probably together with helium). The same amount, one thousandth part of a gram of radium, changes in the same mineral yearly into helium and other elements (lead is indicated as being one, but this has not yet been experimentally confirmed). Hence the quantity of the comparatively rapidly changing element radium is maintained in the earth by its steady reproduction from the much more slowly changing uranium. This accounts for the continued existence, and also for the minute quantity, of such an unstable element as radium at the present day. The search for a mineral richer in radium than the known uranium minerals is likely to prove as fruitless as the search for an El Dorado, and probably for the same reason. The elements are not unchanging and eternal. Over periods reckoned in thousands of millions of years, they all probably undergo natural and spontaneous transformations, and existing knowledge at the present time points to the view that gold is scarce and lead is common because gold is changing more rapidly than lead. In the embracing scheme of elemental evolution which the study of radio-activity has foreshadowed, we see that although an element may be changing far too slowly for a direct experimental detection of the change to be possible, yet inevitably in the lapse of ages these changes must make themselves felt, the more stable accumulating in quantity at the expense of the less stable.

Since we know the amount of energy evolved from a known weight of radium in a known time, and the fraction of the total undergoing change in that time, we can arrive at an estimate of the total energy evolved in the complete disintegration of radium. The energy evolved per gram of radium per hour is 100 calories, and so in one year amounts to 876,000 calories. In this time, between one thousandth and one two-thousandth part changes, so that the total heat evolved during the complete change of one gram of radium would amount to at least a thousand million calories. This is over a hundred thousand times greater than that evolved from a similar weight of coal burning. This calculation, although an experimental one, involves the assumption that the rate of evolution will be maintained over a period of about a thousand years, and is to this extent hypothetical. Even this assumption may be avoided by dealing with the radium emanation, which changes practically completely in the course of a few weeks. The quantity of emanation possible to get is almost infinitesimally small, but is just within the range of measurement. Rutherford has shown that the maximum amount of emanation produced from a gram of radium evolves 75 calories per hour, and that the total evolution before the activity has completely decayed amounts to about 10,000 calories. The actual quantity of emanation was measured by Ramsay and the author, and found to be about one cubic millimetre by volume, and though the density of the emanation and therefore the weight of this volume is not accurately known, the result supports the other estimate.

One cubic centimetre of emanation would evolve ten million calories, and even if the emanation were the heaviest gas known, the weight of a cubic centimetre would not exceed one hundredth part of a gram. Speaking approximately, we may regard the energy evolved during radio-active changes as being, weight for weight of matter considered, between one hundred thousand and a million times as great as that evolved in any chemical change previously known. This represents, of course, but a part of the total internal energy of the radium, being the difference in the internal energies of the element before and after it has disintegrated.

We cannot regard the existence of this large internal energy as a peculiar property of the element radium. Rather we must regard all elements as possessed of stores of energy which, while they no doubt vary for the different elements, are in all cases much greater than is ever associated with compounds. In the first place, radium in its chemical properties is a completely normal and typical element, and possesses a chemical nature almost identical with the inactive element barium. Uranium was known long before its radio-activity was discovered, and represents another perfectly normal chemical element. Yet uranium, since it produces radium with evolution of energy, must possess all the internal energy of radium and more. It is probable that the elements as a class all possess great internal energy, and that their characteristics of stability and permanence, and the failure of all attempts to change them by artificial means, is due to the existence of this internal energy. The forces at our disposal, compared to those which are exhibited when an atom suffers change, are of a different and lower order of magnitude, and it is not to be expected therefore that transmutation will become possible until we can control more powerful agencies than are at present available.

Let us consider in the light of present knowledge the problem of transmutation and see what the attempt of the alchemist involved. To build up an ounce of a heavy element like gold from a lighter element like silver would require in all probability the expenditure of the energy of some hundreds of tons of coal, so that the ounce of gold would be dearly bought. On the other hand, if it were possible artificially to disintegrate a heavy atom like lead and produce gold from it, so great an amount of energy would be evolved that the gold in comparison would be of little account. The energy would be far more valuable than the metal. This enables us to rate at their true value the claims of those who in the past aspired to transmute the metals The charlatan of the future must be even more ambitious than his prototype in the past. In addition to his peculiar metallurgical operations he must be prepared to offer us abundant supplies of light without power, and of power without fuel, or incur "the fate of the half-hearted meddler in great affairs."

But there is no saying, now we are assured we are on the right track, how or when a discovery may not be made which will put into our hands the key which will unlock this great store of energy bound up in the structure of the element. All attempts so far to accelerate

the rate at which the store is being naturally evolved, in the case of the radio-elements, have been unsuccessful.

Let us in imagination overstep this barrier to progress and suppose that a way were known in which the element uranium, for example, which disintegrates to the extent of a thousand-millionth part annually, could be made completely to disintegrate in the course of a year. At first this does not seem a great assumption to make, but see what it involves! From one gram of the element more than a thousand million calories could be evolved, and this, if it could be converted into electrical energy, would be equivalent to more than a thousand kilowatt-hours, and would suffice to keep a 32-c.p. lamp burning continuously throughout the year. By the expenditure of about one ton yearly of uranium, costing less than £1,000, more energy would be derived than is supplied by all the electric supply stations of London put together. One little step, so easily anticipated in imagination, so insignificant even in comparison with all that has been accomplished in the past, divides us from this magnificent inheritance. So we see that transmutation has become a bigger problem than the alchemist dreamed of. He was attempting blindly to do he knew not what. We are starting the twentieth century with the prize in full view, with every factor in the problem accurately and quantitatively known, with the actual process in full operation under our eyes in the laboratory of Nature, and with nothing therefore to be accomplished but the familiar sequence of imitation, improvement, and control.

MANCHESTER LOCAL SECTION.

AN INVESTIGATION INTO THE PERIODIC VARIATIONS IN THE MAGNETIC FIELD OF A THREE-PHASE GENERATOR BY MEANS OF THE OSCILLOGRAPH.

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(*Paper read March* 27, 1906.)

The periodic variations in the magnetic field of a generator and the eddy-current losses to which they give rise appear to have frequently been the subject of mathematical and speculative investigation. In all such investigations, so far as the authors are aware, the E.M.F.'s induced in the pole-pieces, and hence the periodic variations of the magnetic flux, have been assumed to follow the sine law. Direct determinations of the eddy-current losses have also been attempted, but no actual experiments appear to have been made to ascertain the nature and magnitude of the periodic variations themselves.

The present investigations consisted of such actual experiments, which have revealed the nature and magnitude of the variations referred to. The generator employed was 3-phase, star-wound, rotating armature, 10 poles, one tooth per pole per phase, semi-closed slots; it was run at a speed of 837 revolutions per minute, and was excited to give 209 volts on open circuit between the neutral and 1-phase. The full load current was 11 amperes. The excitation was maintained constant throughout the experiments.

For the purpose of the investigation the periodic variations in the field were observed by means of the related E.M.F.'s induced in certain search coils attached to the faces of the poles. These will be referred to as "stationary coils." The E.M.F. induced in an armature conductor was also observed by means of other search coils attached to the armature. These will be referred to as "moving coils." The periodic variations in the E.M.F.'s induced were recorded by one pair of strips of a Duddell high-frequency double oscillograph and revolving film camera.

In order to interpret the records obtained it was necessary to know the exact position of the armature relative to the pole-pieces corresponding to any instant in the E.M.F. wave given by a coil.

The position was ascertained by means of a contact-maker attached to the armature which closed the circuit of the second pair of strips of the oscillograph through a Le Clanché cell once in every period of the machine. The maximum time of contact was about $\frac{1}{5000}$th second. Thus, in the photographic records, there was a small peak on the zero line once in every period, which corresponded to a predetermined position of the armature. A stationary coil of six turns was attached to the two leading tips of adjacent poles, a similar coil to the two trailing tips, and a third to the centres of the two faces.

Three moving coils, each of one turn, were laid in the armature slots similar in their circuit to a loop of the armature winding and respectively at the top, the bottom, and the centre, as shown in Fig. 1.

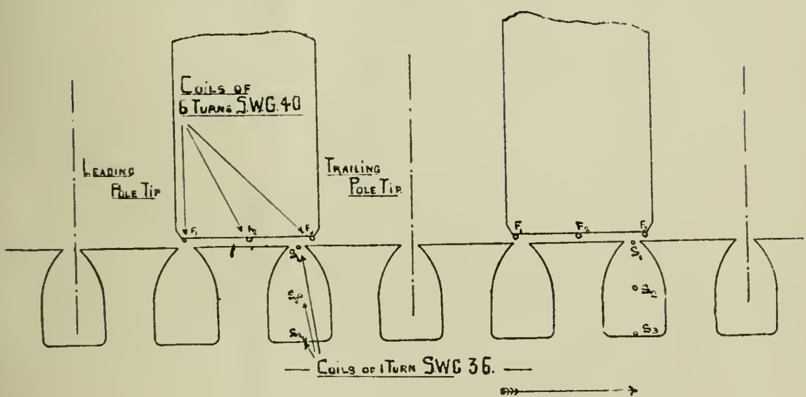

Fig. 1.—Position of the Search Coils.

All these search coils as well as the contact-maker were connected to the generator at the neutral point.

Oscillograph records of the E.M.F.'s induced in the search coils were taken in rapid succession by means of a special switchboard.

The machine was run respectively on open circuit; non-inductive load consisting of liquid resistances; inductive load consisting of choking coils of very small resistance; and capacity loads consisting of mica condensers.

Records were taken at half and full load in each case, except in the case of the capacity, which was at half load only. The three phases were balanced in the case of each load except in that of capacity, and the current in the capacity load was in three phases respectively—5·77 amperes, 6·4 amperes, and 5·77 amperes.

The results of the investigation as photographically recorded by the oscillograph are shown on the accompanying diagrams, and for the

convenience of reference each separate diagram shows the results of one condition of load.

Diagram Fig.	2	gives results from open circuit.				
,, ,,	3	,, ,,	non-inductive load		5·19	amperes.
,, ,,	4	,, ,,	,,	,,	10·49	,,
,, ,,	5	,, ,,	inductive	,,	5·19	,,
,, ,,	6	,, ,,	,,	,,	10·49	,,
,, ,,	7	,, ,,	capacity	,,	6·00	,,

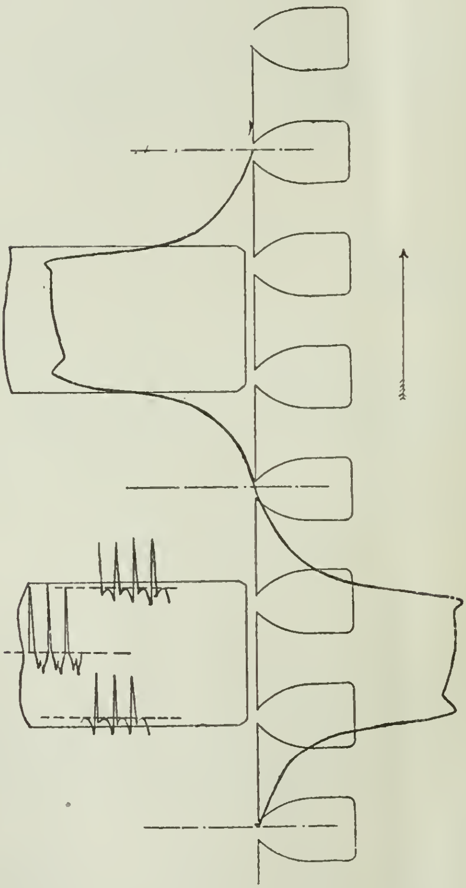

FIG. 2.—Open Circuit.

In all the diagrams the curves which have reference to the stationary coils are drawn on the pole-piece, each on a vertical line passing through the coil to which it refers.

The curves which have reference to the moving coils are drawn on

the surface of the armature in correct relationship to the pole-pieces as shown by the contact-maker.

Although the stationary coils were of six turns, their E.M.F. waves, as shown in the diagrams, may be regarded, like the waves of the moving coils, as those induced in one turn only, but drawn to double the scale.

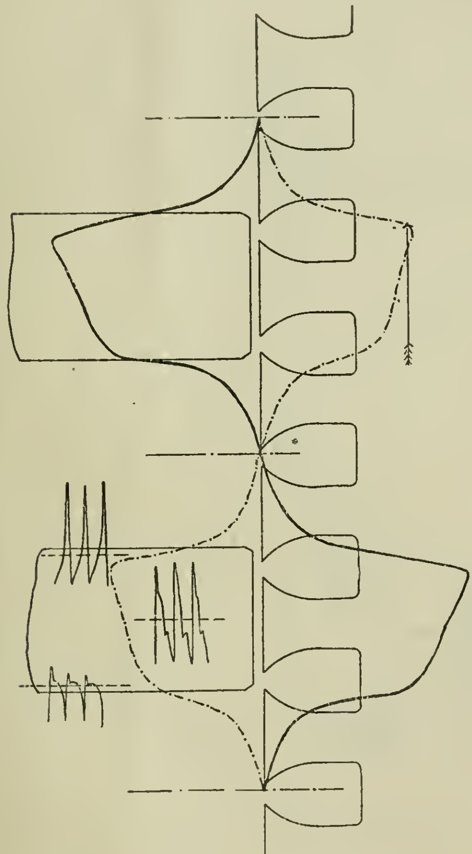

FIG. 3.—Non-Inductive Load, 5·19 Amperes.

For the sake of clearness diagram Fig. 7 is drawn to a slightly larger scale than the other diagrams.

As it was found that the curves from all the three coils in the slots were identical with each other in shape, and only varied in magnitude within the limits of accurate copying, those from one only have been drawn.

The dotted curve on each diagram represents the wave of current in the mains in phase relationship with that of the E.M.F. in the moving

coil at the top of a slot. In the case of the non-inductive loads, however, this curve, for the sake of clearness, is displaced 180°.

In the stationary coil curves six waves were found to occupy the same time as one period of the machine. Therefore, as the frequency of the machine was 70 per second, that of the variations in the field was 420 per second, and, as there were three teeth to each pole, the passage

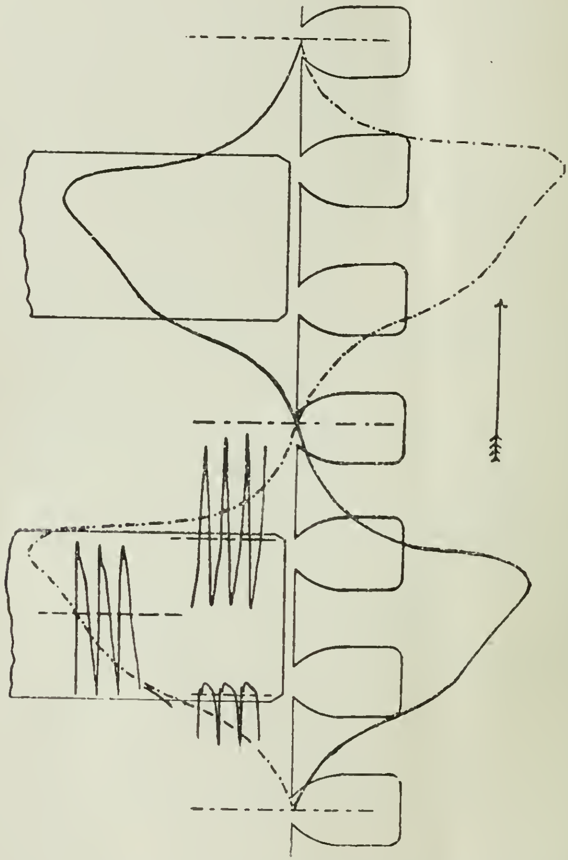

FIG. 4.—Non-Inductive Load, 10·49 Amperes.

of each tooth through any part of the field was marked by the occurrence of one of the periodic variations under investigation. The movements which go to make up one of these variations may be described as a "flash" and a "drag." The flash occurs across the slot in the opposite direction to that in which the armature moves, while the drag occurs in the same direction as the motion of the armature, and is caused by hysteresis effects in the teeth. These flash and drag movements of the flux are apparent in all the stationary coil curves,

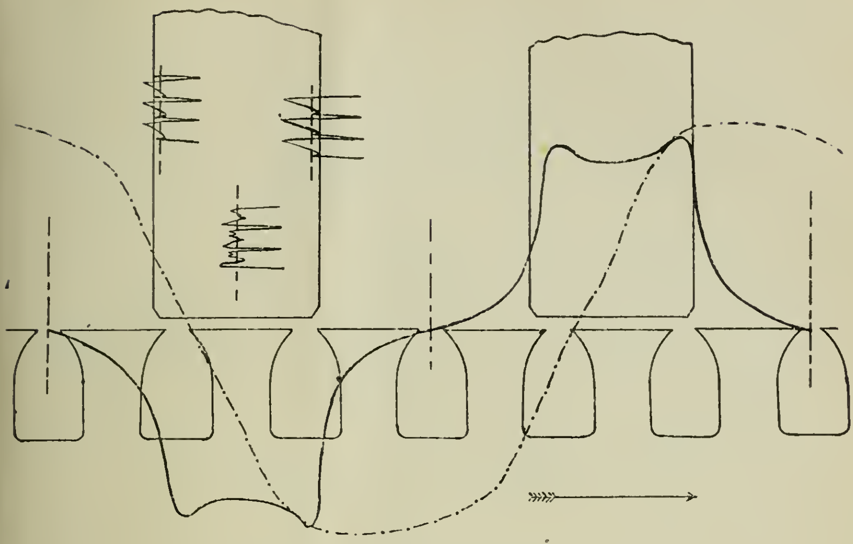

FIG. 5.—Inductive Load, 5·19 Amperes.

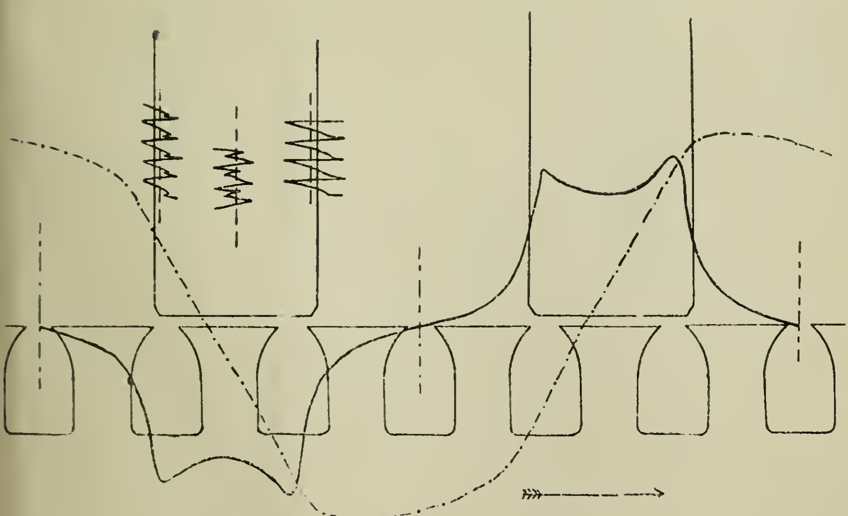

FIG. 6.—Inductive Load, 10·49 Amperes.

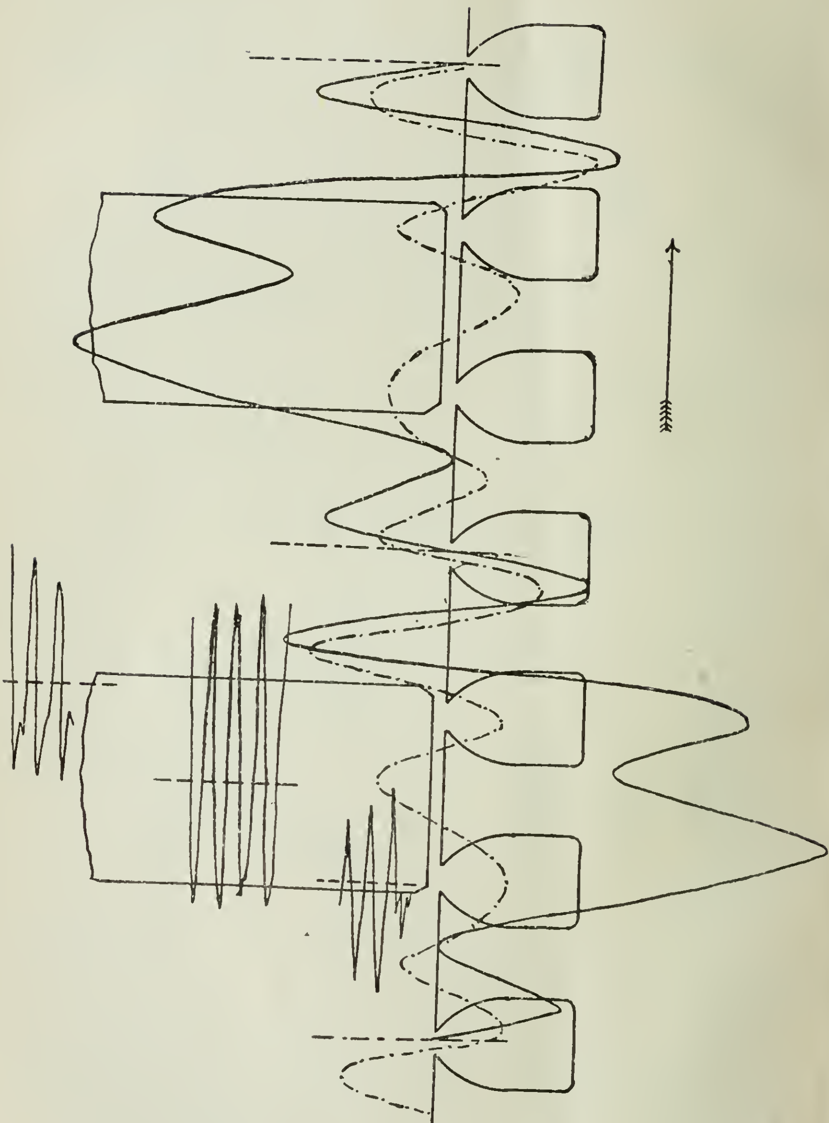

Fig. 7.—Capacity Load, 6 Amperes.

and are distinct from each other, but the distinction is most apparent in the curves taken on open circuit. The E.M.F.'s due to the drag are measured to the left of the zero line, and those due to the flash to right.

In Column 1, Table I., are given the maximum values of the E.M.F.'s induced in a single conductor of each stationary coil under the various conditions of load, and these values correspond with those induced in a pole-piece and available for the production of eddy currents. In Table II. are given the ratios of the same E.M.F.'s to those induced on open circuit.

Table I.

Showing the values of the maximum E.M.F. induced in the pole-piece. Also the ratio of the maximum E.M.F. induced in the pole-piece to the maximum E.M.F. induced in an armature conductor.

	Max. E.M.F. in Volts induced in the Pole-pieces.	Ratio.
1. *Open Circuit.*		
Leading Pole Tip	0·15	0·14
Trailing Pole Tip...	0·18	0·16
Centre of Pole Face	0·25	0·22
2. *Non-Inductive Half Load.*		
Leading Pole Tip	0·15	0·13
Trailing Pole Tip...	0·27	0·23
Centre of Pole Face	0·24	0·20
3. *Non-Inductive Full Load.*		
Leading Pole Tip	0·16	0·13
Trailing Pole Tip...	0·33	0·27
Centre of Pole Face	0·25	0·21
4. *Inductive Half Load.*		
Leading Pole Tip	0·13	0·13
Trailing Pole Tip...	0·17	0·18
Centre of Pole Face	0·15	0·16
5. *Inductive Full Load.*		
Leading Pole Tip	0·06	0·07
Trailing Pole Tip...	0·12	0·14
Centre of Pole Face	0·07	0·08
6. *Capacity Half Load.*		
Leading Pole Tip	0·28	0·16
Trailing Pole Tip...	0·33	0·20
Centre of Pole Face	0·45	0·27

TABLE II.

Showing the ratio of the maximum E.M.F. induced in the pole-pieces under different conditions of load to the maximum E.M.F. induced on open circuit.

	Ratio.
1. *Leading Pole Tip.*	
Open Circuit	1·00
Non-Inductive, Half Load	0·99
Non-Inductive, Full Load	1·03
Inductive, Half Load	0·84
Inductive, Full Load	0·39
Capacity, Half Load	1·77
2. *Trailing Pole Tip.*	
Open Circuit	1·00
Non-Inductive, Half Load	1·50
Non-Inductive, Full Load	1·03
Inductive, Half Load	0·94
Inductive, Full Load	0·66
Capacity, Half Load	1·83
3. *Middle of Pole Face.*	
Open Circuit	1·00
Non-Inductive, Half Load	0·96
Non-Inductive, Full Load	1·00
Inductive, Half Load	0·62
Inductive, Full Load	0·28
Capacity, Half Load	1·80

The area of each of the E.M.F. curves represents the total flux which cuts the coil. For such area equals the product of the rate at which the flux cuts the conductors of the coil and the time of such cutting.

The flash and drag taken together were periodic and their frequency constant under all loads, while taken individually their times were found to be unequal and to vary in relation to each other under different loads. The time of the flash was longer on load than on open circuit. The area of the curve of the flash was in all cases equal to that of the drag—a result which might be expected in the absence of any continuous forward or backward movement of the flux.

In Table III. are given the values of the fluxes moving at various points upon the pole face. It was found that, although the actual values of the fluxes varied through a wide range, yet in all cases, except in those of the inductive loads, the sum of the fluxes moving under the two tips was equal to the flux moving in the centre of the pole face.

TABLE III.

Giving the actual values of the fluxes moving under the pole tips and the centre of pole face.

	Leading Tip.	Trailing Tip.	Centre of Face.
Open Circuit	2,780 ...	2,780 ...	5,770
Non-Inductive, Half Load ...	4,310 ...	8,620 ...	13,400
Non-Inductive, Full Load ...	4,000 ...	15,400 ...	19,400
Inductive, Half Load ...	2,780 ...	4,000 ...	2,780
Inductive, Full Load ...	3,080 ...	4,310 ...	2,780
Capacity, Half Load ...	13,860 ...	9,240 ...	23,100

The actual flux threading the moving coil at the top of a slot when placed symmetrically about a pole-piece was determined by the ballistic method and found to be $5 \cdot 14 \times 10^5$ lines.

In Table IV. are given the ratio of the fluxes given in Table III. to this total flux.

TABLE IV.

Giving the ratio of these fluxes in Table III. to the total flux.

	Leading Tip.	Trailing Tip.	Centre of Pole Face.
Open Circuit	0·0054 ...	0·0054 ...	0·0112
Non-Inductive, Half Load ...	0·0084 ...	0·0168 ...	0·0261
Non-Inductive, Full Load ...	0·0078 ...	0·0300 ...	0·0377
Inductive, Half Load ...	0·0054 ...	0·0078 ...	0·0054
Inductive, Full Load ...	0·0060 ...	0·0084 ...	0·0054
Capacity, Half Load ...	0·0269 ...	0·0180 ...	0·0450

While the "flash" and the "drag" approached equality in time the E.M.F.'s induced by them approached equality in magnitude.

It might naturally appear that the stationary coil curves, leading pole tip, non-inductive loads, Figs 3 and 4, have been inverted. This, however, is not the case, as will be seen by comparison of these curves with that corresponding with them on open circuit. The curves are similar in shape and only differ in respect to the magnitude of their E.M.F. peaks.

All the stationary coil curves have two principal features, *i.e.*, the correspondence in period of six of their waves with one period of the machine and the formation of each wave by one "flash" and one "drag" movement of the flux.

These two features distinguish them from the moving coil curves which have next to be considered. In these the continuity of the "flash" due to the movement of the coil across the pole face destroys the division into periods, and the "drag" being caused by the movement of the teeth does not influence the form of the wave.

By the continuous "flashing" in the opposite direction to the

motion of the armature, however, the height of the wave is increased, but as the flashing varies from point to point of the pole face and with various loads, the increase in height due to this cause is neither constant nor proportional to the flux.

The moving coil curves generally exhibit the well-known effects of armature reaction, but these effects are not apparent in the case of the peaks formed under the trailing pole tip in non-inductive and capacity loads, the height of these being the same as that of the peak on open circuit, and not greater, as might have been expected.

In Column 2, Table I., are given the ratios of the maximum values of the E.M.F.'s shown to be induced in the pole-piece (given in Column 1) to the corresponding maximum values of the E.M.F.'s induced in one conductor of the moving coils, which latter corresponds to one conductor of the armature winding.

From this table it will be seen that even on open circuit the E.M.F. induced in the pole face may be as much as 22 per cent. of the E.M.F. induced in an armature conductor, and on non-inductive full load this value rises to 27 per cent. It will also be noted that, although the E.M.F.'s induced have their largest values in the capacity load, their ratios to those generated in an armature conductor are approximately the same as on full non-inductive load.

It may now be of interest to examine somewhat more closely the periodic variations which have been described. It has already been stated that the variations consist of two movements, a flash across the slot in a direction opposite to that in which the armature moves, and a drag due to the teeth in the same direction as the motion of the armature.

The diagrams all show that the E.M.F. induced in the stationary coils is only zero when the flux is changing the direction of its motion, and during the drag portion of the E.M.F. wave in the coils at pole tips in the case of open circuit. This shows that immediately after a flash the flux swings round with the armature and the inclination of the lines to the pole face gradually increases until the next tooth approaches sufficiently near to cause the flux to flash across the slot. At a given instant, therefore, the flux would be distributed somewhat as shown in Fig. 8.

Another point that is shown very clearly is the difference between the general reaction over the whole pole face due to the current flowing in an armature coil and the local reaction on the tips of the teeth due to the current flowing in an armature conductor.

The general effect is to reduce or increase the E.M.F.'s induced in the stationary coils.

Fig. 9 is drawn to show the local flux produced, the current flowing in an armature conductor. This flux, when the current flows in the same direction as that of the E.M.F. induced in the conductor, tends to strengthen the flux in the adjacent tip of the tooth receding from a point in the pole face opposite to the conductor and to weaken that in the adjacent tip of the tooth approaching the same point. The result is that the flash commences earlier and is, therefore, slower in action.

By this means the E.M.F. induced in a stationary coil is reduced and the duration of the flash becomes more nearly equal to that of the drag. The reaction described takes place when the direction of the current in the armature conductor is the same as that of the E.M.F. induced, and this coincidence of direction of current and E.M.F. obtains in the case of all loads when an armature conductor is opposite the trailing

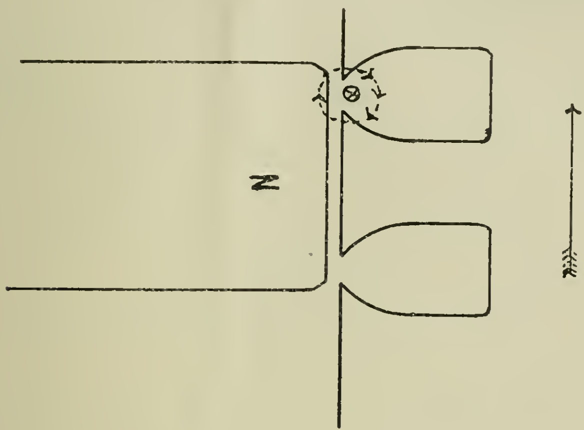

Fig. 9.

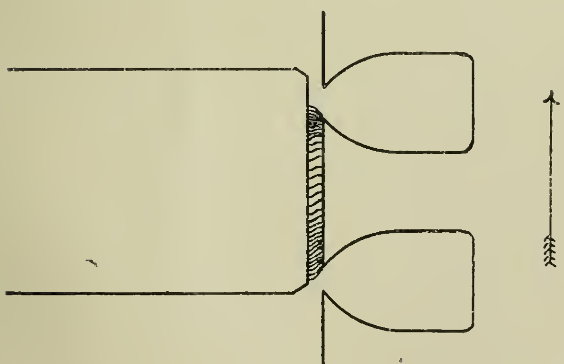

Fig. 8.

pole tip, and the trailing pole tip curves exhibit the tendency towards equality referred to of the flash and the drag when the machine is under load. Some of the other curves also will be found to exhibit a similar tendency.

It occurred to the authors that the periodic variations in the field might possibly penetrate beyond the air-gap into the main magnetic circuit, but this was found not to be the case, for, on connecting with

the oscillograph, two coils each of six turns wound respectively round a limb and yoke of the magnets and running the machine on capacity load, no variations were recorded.

In conclusion, the authors desire to express with gratitude their indebtedness to Professor E. W. Marchant, in whose laboratories the experiments in connection with this paper have been performed, and who has aided them at every stage of their work with his valuable criticism and suggestions.

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BIRMINGHAM LOCAL SECTION.

NOTES ON OVERHEAD EQUIPMENT OF TRAMWAYS.

By ROBERT N. TWEEDY, Associate Member, and H. DUDGEON.

(*Paper read February* 14. *Rediscussed in London, May* 17, 1906.)

INTRODUCTION.

Perhaps there is no part of a tramway which has received greater attention than its overhead construction ; nor is this to be wondered at, for certainly there is no part which has been subjected to greater criticism by the general public, and to more intemperate criticism by those who were interested in some system in which the overhead wire and all its supporting paraphernalia are displaced ; and, on that account alone, it has been a great point with tramway engineers to lessen the possibility of these criticisms by doing all they can to introduce improvements in detail, with the result that serious accidents arising from the presence of overhead work have become rarer and more rare.

Such accidents never were common even in the earliest days, and we venture to say that if Liverpool had not seen that February day in 1901 when a heavy stack of telephone wires fell across the trolley-wires with fatal results, it would not have required a tithe of the time to demonstrate to the public that there is not something essentially and menacingly dangerous about the trolley-wires that traverse so many of our streets.

As a matter of practical fact, great danger has never attended the fall of a trolley-wire, although we do not expect that statement to be accepted by the layman.

Proof of it is found in the refusal of tramway engineers generally to install any of the numerous, ingenious, and costly safeguards of which they have had their choice for some years ; but the best proof of any is derived from vital statistics which show that there have been no more than four fatalities due to the presence of overhead con-

struction in our streets, and of those four the Liverpool accident accounts for two.

The real danger, however small it may be, as every tramway engineer will admit, has lain, and still lies, in the fall of message wires, and of the guard-wires which are placed compulsorily between the trolley-wires and those message wires. The overhead system has had to bear the blame which should have been visited on the faulty message wires; but that is ancient history, and it is mentioned only to bring out the better the improvements which have been made of late years. The sense of danger has reacted so strongly on the Board of Trade, the tramway proprietors, the National Telephone Co., and the Post Office, that stringent regulations have been framed by the first and carried out with much grumbling by the second, while the third have done what they could to remove the real causes of offence whenever the tramway proprietors were not unreasonable, and the fourth have been very busy improving their lines and keeping the tramways up to the very letter of the regulations.

That reaction has proceeded for some five years, with the gratifying result of almost complete immunity from accidents, not necessarily personal, which at one time were numerous, though for the most part trivial in their effects.

Undoubtedly guard-wires have been of some service in the intended direction; while once at least they were the means of keeping the cars running over a stretch of line which else had been severed as to its negative side from the power-station. They manfully bridged the gap which a thoughtless permanent-way foreman had made in the rails.

The factor of safety of sound overhead construction is well illustrated in one of the series of admirable reports which it was the custom of the late Mr. C. R. Bellamy to submit to the Liverpool Tramways Committee. During a gale which raged on December 31, 1902, a tree was broken off about 18 ft. from the ground, the trunk measuring 13 ins. diameter at that height. Although the trolley-wires were brought nearly to the ground, they did not break, and traffic was resumed within seven and a half minutes of the occurrence. Many instances have come under notice in which careless driving, or a defect in the overhead work, or in some part of the trolley, has resulted in the heavy cast-iron trolley-standard being snapped in two after fouling the trolley-wire, while the overhead construction has not appeared to be damaged in the least, although the commotion among the poles has been fearful to behold. Fortunately that kind of accident has been reduced to a pleasant infrequency, to be ascribed largely to the calm influence of the Board of Trade, which called for detailed monthly reports of accidents of this nature (among others), and insisted on the adoption of the best-known precautionary measures.

If the excursion of trolley-poles amongst the trolley and guard-wires can be written down as "practically impossible," the plea for lighter construction which is made later in this paper will be given much greater weight. The number of such accidents is ever on the wane, and the general use of the retrieving devices, of which there are

several on the market, would bring it down to as near zero as we may expect to get.

While the capital cost of tramways in Great Britain runs between the extraordinarily wide limits of £10,000 and £24,000 per mile of single track, the cost of overhead equipment may be taken as varying, equally widely, between £700 and £2,000 per route-mile.

While not by any means the most important constituent of a tramway from the financial aspect, it is nevertheless highly desirable that in these days of weeping for past extravagances every nerve should be stressed to reduce the cost of each portion of a tramway, and it is one of the chief objects of this paper to elicit discussion as to the best means of effecting this end with relation to the overhead construction. That reductions can be made, although perhaps not on the lower limit quoted above, we have no more doubt than that the consumption of coal per kilowatt-hour is still too great in our central stations.

There is not a great deal of published matter relating to English overhead construction and maintenance.

Mr. H. M. Sayers read a valuable paper before the Tramway and Light Railways Association in January, 1905, and Mr. McElroy rendered considerable service by compiling for the conference of the Municipal Tramways Association in Liverpool, September, 1904, a comprehensive array of facts gathered from all over the kingdom.

On a subject which might arouse so much enlightening controversy if properly treated, it is a pity that so little should have been said.

Poles.

Now that the British Standard Committee has recommended a certain series of poles for general use, most people consider that the subject ought to be buried for a decent period; but if this is admitted, by the time that the indefatigable Committee has standardised everything there will not be anything left to discuss, and half the use of such institutions as this will be gone. At the same time we feel that any criticism of the Committee's recommendations might be construed as criticism of the Committee itself. Needless to say that is a construction which we should deplore.

A contributor to the discussion of Mr. Sayers's paper expressed an opinion which was strong, if nothing else, that the standard poles are all too light for their work, and we have heard from other users an identical opinion of the lightest standard, but in no case does the complainant show that the poles were not abused—were not, that is to say, subjected to greater stresses than their specification admits as safe; and it is highly probable that this is actually what caused the poles in question to give way. Moreover, it must be remembered that the Committee merely specified the *minimum* thickness of the metal, so that it rests with every engineer to strengthen his poles within certain limits while keeping to the standard dimensions.

We disagree so much with those who say that the standard poles are too light as to assert, indeed, that they can be made lighter without sacrificing safety or any other desirable quality.

The tendency during recent years has been all in the direction of increased strength and therefore weight of poles, while it seems to us, at least, that the greater cost entailed is not warranted. For instance, a certain line was constructed under three contracts. One length of 3 miles is all span wire, and the poles are 29′ 0″ to 29′ 6″ long, built up of three sections $6\frac{1}{2}'' \times 5\frac{1}{2}'' \times 4\frac{1}{2}''$, out of steel $\frac{1}{2}''$ thick. Another equal length has poles $31' \times 7\frac{1}{2}'' \times 6\frac{1}{2}'' \times 5\frac{1}{2}'' \times \frac{1}{2}''$ for all straight-line work, whether span, side-bracket, or centre-bracket construction; while the third contains centre, side-bracket and span poles which are all taper $6\frac{1}{2}'' \times 4\frac{1}{2}'' \times \frac{3}{8}''$. Here we have poles of very different sizes doing the same work under the same conditions, and the smallest stand up just as straight as the others. All the sizes cannot be right, and it is plain that, if they are all satisfactory, the smallest is economically the best (see Appendix, p. 184).

Then the question arises, Is the smallest small enough? First let us see what has determined the size of poles on British tramways. The earliest examples are Leeds, 1891, with light 2-section poles, $7'' \times 6'' \times 4\frac{1}{2}'' \times \frac{1}{2}'' \times 29'\ 6'' \times 920$ lbs., and heavy 2-section poles, $8'' \times 7'' \times 4\frac{7}{8}'' \times 29'\ 6'' \times 1{,}300$; and South Staffordshire, 1893, where on the side-bracket system throughout the taper poles for ordinary construction were $6'' \times 2\frac{1}{2}'' \times \frac{1}{4}'' \times 450$ lbs., and for use at loops with longer bracket-arms they were $7'' \times 3\frac{3}{4}'' \times \frac{1}{4}'' \times 560$ lbs.

The Kidderminster and Stourport Tramways (1898) afford another instance of a line which had to be constructed in the cheapest fashion if any dividend was to be earned, and the poles here are $28'\ 6'' \times 6'' \times 3'' \times \frac{1}{4}''$, and $29'\ 3'' \times 7'' \times 3\frac{1}{2}'' \times \frac{1}{4}''$ at loops, the weights being nearly the same as the South Staffordshire poles.

Not only were these poles (which look so airily light to us now that we are too well accustomed to larger) used, but they were quite large enough for the work, and the South Staffordshire poles have borne testimony to this for twelve years.

At the opposite extreme comes West Bromwich, with poles which are monstrous beyond belief (see Appendix, p. 186).

There is no desire to draw a strict comparison between the Leeds and South Staffordshire poles, because much of the Leeds work was span-wire, while the South Staffordshire bracket-arms are very short; nevertheless, where centre-poles and short side-brackets were used in Leeds, one of the South Staffordshire poles would have been almost, if not quite, large enough.

Then we may take Bristol and Dublin, where as many as five different sizes were used in the original construction (P. Dawson), the smallest of them having to stand a lateral strain near the top of 350 lbs., and the others 500, 700, 1,000, and 2,000 lbs. respectively.

The last size may be left out of consideration of the general problem, as it is used for anchoring purposes only. That leaves the 350-lb. pole for the lightest work, the 500 for longer brackets and for straight-line spans, the 700 for somewhat similar duty and for heavier spans and light curves, while the 1,000-lb. pole would be left for all but the heaviest curves and anchorages.

As tramways have increased the three light sizes have dropped out almost entirely, and engineers begin now with something like the 1,000-lb. pole.

The Americans have to stand a deal of blame for our faults, and we believe that our predilection for heavy poles is due in great measure to that nation. Pole-planting in the early days of American street-railway work was a simple matter. They took any kind of tree, lopped off most of the branches, stuck it into a hole by the side of the road at an angle of anything up to 45° from the vertical, threw in the ballast that happened around, stamped on it once or twice, and then, by stretching a span between a pair, pulled them up sufficiently to keep the trolley-wire clear of the single-deck cars. Linesmen trained in these practices came over to put up our lines for the American contractors who did most of the work for the first few years, and they did their best to pull big rakes out of poles set in concrete. They had very little idea of planting the poles with just enough rake to bring them vertical by straining up the span-wire to any required degree, the primary idea being to pull out of the poles any rake that the individual linesman, educated as above, thought fit to put in.

The hasty, shoddy work to which the men were accustomed led them to believe that a foot of rake was none too much, unless the hole was got out of solid rock, in which case 6″ might be enough. Such rakes were used regularly, and are put in to this day by many linesmen.

In our careful British way we used to give the constructional linesmen spring dynamometers to put in series with the pull, but they broke when this exceeded 600 or 700 lbs., and the rest of the rake was removed without the aid of an indicator. The main thing was to get out the rake. It may be imagined what a bad reputation was given to the lighter poles—a reputation which has led finally to the standardising of poles which are too heavy. If we had been contented with dirt and rocks for filling, the rake would have come out all right even with the small poles; but we filled with 6 to 1 concrete, and the cost of construction per mile has suffered much as a consequence.

If engineers could persuade themselves that 18″ sag in a 30-ft. span and 2 ft. across a 40-ft. road is neither unsightly nor detrimental, and would insist that the span-wires are not pulled up any more than that, they would find the light poles which they have cast aside strong enough for 75 per cent. of the construction, allowing heavier poles for curves and the like on 25 per cent. of the line (see Appendix, p. 184).

In average ground, with half a yard or so of concrete round the pole, 1″ to 2″ is quite enough rake to allow when setting. As an example of this the following facts are to the point: It was necessary to move back poles on one side of a road. They were planted and pulled up straight, when the sag in the spans was about 18″. The poles on the other side, which were plumb before their fellows were removed, now had a positive rake of $2\frac{1}{2}$″, and the untouched spans just beyond the alterations sagged about 12″ with vertical poles.

Probably, therefore, that was the original state of the altered spans, so that this instance is not as good from our point of view as one in which the span-wires were pulled taut, although even here each pair of poles was given at least 5″ more rake than was required.

Assuming that the South Staffordshire poles are too light to be safe even for bracket-arm work, what a gulf there is between their 450 lbs. and the 1000 to 1,500 lbs. of the poles now in most common use! Then consider that a pole which is too light for a 10-ft. bracket-arm may be quite big enough to divide with another the weight and other stresses of a 30-ft. span.

For the average width of street the 500 lbs. (lateral strain for 6″ deflection) pole mentioned in connection with Bristol and Dublin is heavy enough for straight-line work if used in the proper manner. It is not unreasonable to estimate that a saving of £200 per route-mile can be made by following this advice.

The height of all the standard poles is 31′, but there are many instances, which will increase as the use of guard-wires declines, where shorter poles would be as good. That is eminently the case in centre-pole and light bracket-arm work, where it is unnecessary to bury 6 ft. of the pole, and, indeed, we have found a depth of 5 ft. sufficient in straight line span-work of average weight.

Let us not continue from sheer force of conservatism to use 31′ poles when something nearer the Board of Trade limit is sufficient.

Concrete.—When poles are subjected to less strain the quality of the concrete setting may be reduced. This costs at present about 9s. per pole for labour and material, and it is usual to find that one bag of Portland cement is allowed per pole. This charge may be brought down to 5s. or 6s. with equal results, and, even with excessive tension on the span-wire, half a bag of cement has been found enough. Naturally, the materials for the poorer concrete must be good; the broken bricks, stone, slag, or gravel, clean and wet; the sand sharp and clean, and the whole mixed thoroughly and allowed to set for a week or more.

Bases.—Must we believe that the cast-iron base which now "protects" the tramway-poles in this country is so set in the affections of the people, is so much part of their daily scenery, that to lift up our voices against it is akin to sedition and heresy? A cast-iron base on a tramway-pole is of as much use as a diamond ring on a lady's finger. Originally intended to protect gas and electric light standards, themselves of cast iron, it was retained by force of habit when the steel tramway-pole invaded the footpaths. Something which breaks with comparative ease is set to protect another thing so firmly embedded and so stoutly made that any accident which displaced or broke it certainly would not be averted or mollified by the presence of a cast-iron base (see Appendix, p. 187).

If the practical utility of the base goes by the board, what else is there to warrant its continued use? Its beauty? There is no accounting for tastes, but we suggest that from six to twenty tons of cast iron per average mile of tramway, serving no practical purpose

whatever, is a luxury which a struggling business would do well to eschew.

But, not only is the base no good, it is actually a negative good : it produces expense. It is usual to bury some inches in the ground and to make a watertight joint at the top. Thereafter it is not moved, while underneath its prosperous and well-painted exterior the most important section of the pole is going to the dogs.

After a pole is erected and the base is in its place, the invariable practice is to clean both and to give them two or three coats of good paint ; and if they are to be kept in condition another coat must be given every year. The pole under the base does not even get the first attention, soon loses what remains of its "shop" coat after the rough treatment of erection, and peels off skin after skin of oxide. True, this part of the pole is not exposed to the weather like its more fortunate remainder, but it is exposed to atmospheric moisture, and with serious results.

An average base costs from 15s. to 20s., depending on its weight and ornamentation. Many Corporations have gone in for bases 5′ and 6′ high, decorated profusely with arms and all kinds of pretty designs ; but we may leave these out of the question as wilful extravagances, and assume that the average base weighs from 300 lbs. to 450 lbs.

If this luxury were relinquished it would make a difference of at least £45 per mile of route for bases alone, excluding materials and labour for caulking, and cost of extra labour and carriage entailed by their presence. Probably the best part of £100 per route-mile would be saved as an average over the whole kingdom.

Ventilation of Bases.—If bases are not to be given up, let them at least be drained and ventilated, and if possible let them be designed and erected so that they may be lifted out of the way, to allow the hidden part of the poles to be painted. It is better to steady and centralise the base with distance pieces cast on than to do any caulking, so leaving a passage for air and water. The water must be drained off, and that is facilitated if the concrete setting of the pole is raised in the shape of a cone above the surface of the road or path. With an annular space at the top and drainage at the bottom, there is a thoroughfare which will prevent or minimise sweating. Far better is it to leave off the bases altogether, even to be so literally iconoclastic as to break off existing bases and sell them in aid of the depreciation fund for which our children will look with lamentations.

Ventilation of Poles.—This question of ventilation applies with almost greater force to the poles.

The necessity for ventilating such closed spaces is acknowledged by every one who designs a feeder pillar. If the vents at the top and bottom or at the bottom only are stopped, the state of the switch-panel and of the switch-handles soon tells its tale.

Samples on the table will demonstrate more effectively than words one of the evils arising from non-ventilation. These pieces of armoured cable—what is left of them—have been removed from watertight pipes leading from pole to feeder-box. No water could enter *viâ* the box,

nor at the joint between pole and pipe, nor could it pass from outside by the cables at the top, as these are too well bushed, but the cables may conduct to the pipe the moisture which is deposited on them by sweating ; and the fact frequently observed when pulling out the cables, that they are covered with slime from top to bottom, makes this source of moisture indisputable. The cable-pipes end in an easy bend, taken into the pole with the end upwards.

Notwithstanding all these precautions the pipe filled with water in the course of three or four years, and the cables finally broke down through the armouring to earth.

The same thing has occurred within our knowledge many times, and during the investigation of the failures from one to several feet of water were found in the poles, and in view of the way in which the poles were set, it is improbable that this water found its way in from the bottom.

The question of sweating seems to require further investigation, for it is important even when the feeder cables are made of such materials and are treated in such a manner that damp will not affect them, as the poles are reduced gradually by oxidation. Suitable ventilation top and bottom ought to do much to overcome this trouble, and it would help matters to coat the interior of the pole with Angus Smith's compound after manufacture.

Experience gathered from various quarters seems to show that "side feeders" or "section cables" should be taken out of the pillar somewhere near the top, passing to the pole in a pipe at that level. Heavily taped and braided I.R. or V.B. cables are better than lead-covered paper cables, and armouring is unnecessary and objectionable. Sometimes for the sake of appearance two cables are brought out of a pole at each side of the road (span-wire construction), sealed off near the poles, and continued to the section insulators as copper wires attached to the span-wire by porcelain insulators. As a rule, side feeders are put in by the contractor for the overhead equipment, but they would be safer in the hands of the cable contractors.

Collars.—Another luxury, for which there is no more excuse than the base, and to which the objections are even stronger, is the C.I. collar which conceals the joints in sectional poles. There are two per pole, costing from 2s. to 3s. 6d. each, averaging perhaps 2s. 6d. These trinkets, for they are nothing else, run to £30 or so per average route-mile, and are worth saving on that account alone. They are nearly as elegant as warts on a tree trunk, and merely substitute their own ugliness for the ill-looks, supposed or actual, of the returns made by the junction of the sections ; but we are used to them, just as the natives of Central Africa are used to adorning their lips and noses with wood and metal. Like the bases, these collars are rarely, if ever, lifted to paint the hidden parts of the pole, and few people know that they catch and hold rain. If they are examined, many are found to be broken. This follows on the entrapped water freezing. As many as 82 per cent. of the collars on one stretch of line were found in this state. Lift them and a mass of rust is disclosed. The rust holds

water like a sponge, and the pole, especially at the joint, is attacked continuously in this insidious manner.

If collars are to remain, it is important that they be drained, and that the parts of the pole beneath shall be painted as regularly as the remainder.

The last vestige of utility would be taken from pole-collars if the swaged joints were finished taper instead of square,* so forming a watershed as well as a pleasanter sight; but we have little hope that these arguments will tell when we observe taper poles, having no asperities to hide, garnished with collars also.

Life of Poles.—It has become usual to talk of steel poles lasting thirty to forty years. We have given certain reasons for thinking this estimate to be exaggerated, and much has been made of the various faults, because the life of tramway-poles is a very serious matter indeed. It may not affect those companies which hold their lives on a twenty-one-years lease, but it does affect every local authority which is a lessor or owner of overhead tramways, and attention to the causes of vital decay should increase the useful life of steel poles by an indefinite amount.

Section Pillars.—These may be set on damp-courses with advantage, and the entrance of the cables should be well sealed. It is the practice of some contractors to fill the base of the pillar with bitumen, thus surrounding the cables whenever they leave through the bottom.

Span Wires.—For the very reason that poles are too heavy, span-wires tend in that direction also. High tensile strength and good galvanising are greater considerations than any other, and 7/15 or 7/14 make strong enough spans for all but very heavy work. Under particularly bad conditions, as, for instance, near chemical works, special precautions have to be taken (see Appendix, p. 187).

Bridle and Pull-off Wires.—The steel wire attached to "pull-offs" should be tied firmly to the eyes, otherwise they become abraded in time, owing to the lift of the trolley-poles. If thimbles are used, they take the wear and are satisfactory.

Guard Wires.—There is little chance of too little guard-wire being erected now that vigilant eyes are on every tramway near which run Post Office wires, but there is some risk that more than are necessary may be put up or left up. Post Office and National Telephone Company wires disappear silently and without notice, and guard-wires which are a potential danger may be left standing until an accident occurs.

Guard-wires should be tied in at every span to localise breakage, not tied merely to keep them in position relative to the trolley-wires. Clamps to perform this duty are sold, and many are in use, but, for the reason which will be given when dealing with "hangers," they ought not to be made of gun-metal. Much trouble from broken guard-wires has resulted from this practice. If clamps are favoured against the simpler, cheaper, and as effective binding-in, they should be made of malleable iron.

* Messrs. John Spencer, Ltd., inform us that to finish the joints taper is impossible, except by the prohibitively expensive method of turning.

It is permissible to insulate such portions of guard-wires as lie above specially dangerous points, but proper attention to the overhead construction and the adoption of suitable retrieving trolleys ought to make that kind of thing unnecessary.

Hangers.—The use of bronze or gun-metal fittings throughout the overhead equipment has become second nature in some engineers. Other things being equal, gun-metal is the nicest material for the work. It is not liable to rust, and its constituents can be mixed in any proportion to suit the engineer, while it is considered an eminently safe metal when well made. But other things are not equal.

Malleable iron, when made as it should be and as it can be made, is nearly as strong as gun-metal, and is quite as safe in the sizes ordinarily used. Malleable iron goods must be well galvanised before use, and ought to be painted once every two years or so after the first three to five years, except in special circumstances.

Current nett quotations compare as follows :—

TABLE I.

	Bronze. s. d.	Malleable Iron. s. d.
Straight line insulator castings	2 3	0 10½
Single pull-off „ „	2 7½	1 0
Double „ „ „	3 1	1 1½

The difference in favour of malleable iron being :—

TABLE II.

	s. d.	
Straight line castings	1 4½	or 61 per cent.
Single pull-off „	1 7½	„ 62 „
Double „ „	1 11½	„ 63½ „

One maker says that the malleable iron fittings are satisfactory "where economy is the object." Another says: "It is almost impossible to recommend one particular type of insulator (casting), as it depends on the conditions for which the insulator is required." And a third writes: "As you are no doubt aware, a large number of tramway engineers declare that it is impossible to use malleable iron fittings in this country, while, on the other hand, a large proportion of others use malleable iron with satisfactory results."

Where is not economy the object? Nobody would dare to say, even if he knew. Economy without the sacrifice of safety can be obtained by the use of malleable iron fittings, and the saving per route-mile will be something like £8 if we assume 100 insulators per mile.

Local Action.—Malleable iron hangers have the advantage over those made of bronze that no local action occurs between the span-wire and the hanger. This action has not received notice hitherto, but it is marked, and is the cause of serious weakening of the span-wire.

An excellent instance of this action has come under the direct observation of the authors. On the whole of one route 5½ miles

long the hangers are of bronze ; on another route 4 miles in length, and a branch of the first, they are of galvanised malleable iron. While the span-wires where they clasp the bronze hangers are practically eaten through and have broken in several cases, the galvanising of the span-wires under the malleable iron hangers and on the hangers themselves is as good as it was when put up. That is conclusive evidence against the decay of the first span-wires being caused by rust. The same action occurs wherever the span-wire is attached to secondary insulators in which the eyes are of brass.

Insulators divide themselves into two classes, primary and secondary. Of primary insulators, that most commonly used consists of an insulated bolt contained in a metallic waterproof casing, of which the composition has been discussed above. The insulated bolt is exposed from beneath to driven rain, to rain splashed from the trolley-wire ear, and to water thrown during rain from passing trolley-wheels, the last being the most serious, and, until recently, the most unexpected. Water thrown from trolley-wheels contains conducting matter like copper dust from the trolley-wire, brass dust from the trolley-wheel, and graphite or oil from the trolley-wheel bush or bearing ; and it is to that extent at least undesirable, as it must deposit in time over the insulated surface of the bolt a conductive layer. But, apart from the deleterious action of the suspended matter, the water itself is injurious to the insulation, as we shall attempt to show.

The failure of hanger-bolts has been accepted as inevitable, and has been ascribed generally either to bad material or to climatic or local influences, and the fact that the evil is the growth of years has made this view tenable until now.

The first bolts were, and those most commonly used now are, of steel ; comparatively lately the steel has been galvanised, and an alternative in the shape of a gun-metal bolt has been introduced. In all cases the average radial thickness of insulation is $\frac{3}{16}$ in., while the length of leakage path runs from 1 in. to $1\frac{1}{2}$ in. The reduction of this leakage path begins from the day of erection, and, sooner or later, depending in some unknown degree on local circumstances, every bolt must fail. The trouble with them on the older lines has been acute, and recourse is had to all manner of shifts to overcome it.

First of all, moisture attacks the exposed end of the bolt, and a semi-conducting film is deposited over the whole insulating surface. That may take a year, or two years, or in exceptional circumstances it may take no longer than six months. But the really dangerous action starts when the rust eats under the insulation from the exposed end. Gradually and imperceptibly that process goes on until the cylinder of compressed insulation begins to swell and to crack under the pressure of the increased volume beneath it, and at length there is no effective insulation at all except the $\frac{3}{16}$ in. radial thickness between the bolt and the hanger casing. A little more and that is bridged, with perhaps disastrous result.

To galvanise the bolt but lengthens the period over which this cycle of fate takes place ; it does not stop it. Obviously the cure should be

to use brass bolts, which do not oxidise appreciably. Why, then, is the fact well authenticated that brass bolts fail even more frequently than iron bolts?

Hitherto we have assumed that oxidation aided merely by deposit from the trolley-wheels is sufficient to account for the behaviour of iron bolts. Now we must bring some other force into the arena, and its name is Electrolysis. That force is the main factor concerned in the destruction of both iron and brass bolts, although at first sight plain oxidation seems to be enough to account for the failure of the iron bolts as explained above, and we will leave them for the time in order to consider the history of the brass bolt. Imagine slight leakage occurring over the insulated surface. In the presence of an electrolyte supplied by the trolley-wheels, if by nothing else, particles of brass are carried down the stream and become deposited by degrees over the whole surface, leading finally to failure of the insulation. In the case of the iron bolts the same thing happens, but the deposit of pure iron is oxidised almost immediately and does not afford a good path.

That very fact accounts for the remarkable spreading of the oxidising process, as exemplified by specimens on the table. If the finely divided iron did not oxidise, the quarry from which the supply is taken would be deepened, while remaining fairly local, until a sufficient film to cause a breakdown is deposited over the insulation, as in the case of the brass bolt. But after every attack the eroded surface oxidises as well as the deposited film, and raises the resistance of the affected surfaces, so that the next attack has to be made from another and easier quarter. These operations recur continually, and their field constantly widens until the metal under the bolt is reached and succumbs in due course. Directly that happens the insulating cover begins to rise off the bolt, and time only is needed to fissure the cylinder and effectually to reduce the leakage path and the speed of the action (see Appendix, p. 185).

An interesting specimen of a complete hanger with ear attached, which was removed from the line before failure occurred, shows to what a degree this action may go without serious consequences. Undoubtedly during wet weather the leakage across this hanger was considerable.

A length of 5 miles was equipped with brass bolts; another of 4 miles, in a much less pure atmosphere, but within the same 10-mile circle, had iron bolts. Neither were backed by secondary insulation, except such as might be afforded by sleeves of fibre. During heavy and continuous rain it was always the former line from which came reports of "live poles," although many of the iron bolts had the appearance of being useless as insulators from the way in which the coating was split. It was a noticeable fact that brass bolts lasted for a shorter time, and failed even more suddenly than iron bolts (see Appendix, p. 187).

In the present state of our knowledge it is unnecessary to examine or to test the bolt to see whether it is about to fail, but of that we shall speak later.

The specimens on the table will give a clear idea of the process of the deterioration and final destruction of the insulating properties of hanger bolts. The remarkable increase in bulk of the iron, caused by oxidation, is particularly noticeable.

There are three ways in which these troublesome and expensive failures may be prevented or alleviated.

First of all, we believe that prevention can be obtained by the insertion of a shield* between the trolley-wire ear and the hanger, in order to keep the bolt dry. The trolley-wheels cannot then throw water into the interior of the hanger, and neither rust nor electrolysis can corrupt.

Secondly, the form of the hanger may be altered, making it nothing more than a metallic link between the ear and the span-wire, and providing for insulation by means of two (three per span) external and independent insulators. Lastly, the hanger may be composed of homogeneous insulation, such as glazed porcelain, something in the shape of a cable sealing-end, through the centre of which a plain metal bolt is passed (see Appendix, p. 187).

Whatever form the primary insulator takes it must be kept dry, or leakage and carriage of metal will start. Therefore, this porcelain insulator should be provided with a hood of some light material to guard it against rain, and with the shield mentioned above to prevent access of moisture from the trolley-wheels.

Secondary Insulators.—Those in most general use are of three kinds, known respectively as "Brooklyn strains," "turnbuckles," and "globe strains," with a fourth, the porcelain reel, coming into favour.

The first two are adjustable. The origin of things is always interesting. Here again, as with the pole bases, the collars on taper poles, and the rake on poles, these adjustable insulators continue to be used long after the reason for them has vanished. Actually they were never wanted in England. They are other things for which we have to thank America, and they serve to illustrate our remarks on pole-planting as it used to be practised over there; for it is evident that poles set in yielding material will tend towards the vertical so long as there is any weight between them, and after a line was erected it was accepted as a normal proceeding that this movement of the poles should be followed by screwing up the turnbuckles or the "Brooklyns" until the span was tight enough for the engineer. When the screws on either side would take up no more, the span was cut and shortened, and another cycle of operations began.

No English linesman wants such devices during the erection of a line, and after this is once done there is still less necessity for them. Nevertheless, both types have been used by thousands, and the illustrations of new lines which appear in technical journals clearly show that their use continues almost unabated. Quite recently an eminent firm of consulting engineers specified "Brooklyns" for the secondary insulation of short flexible suspensions, at a considerable extra cost over the non-adjustable types.

* British Patent No. 13062/05.

It is an axiom that adjustable insulators are not required anywhere on the overhead equipment of a tramway.

Of the other type, that is to be preferred which is the most homogeneous, and has least parts of any kind, and of metal in particular, while giving at least equal results in other ways. On every account the porcelain reel is the one to use. Even as made for the first lines which used it, excellent results were obtained, and, as may be seen by one of the exhibited specimens, its dimensions were regulated by the clearances of existing pole-straps. Possibly the engineer who designed them thought he would have difficulty enough to persuade his directors to sacrifice the old insulators without trying to squeeze new straps out of them also.

Born under adverse conditions, this insulator has withstood the unclean atmosphere of the Black Country and of the Potteries with remarkable success, and in the larger form shown here it need fear no more expensive competitors.

While in malleable iron the smallest "globe strain" can be bought in large quantities at 8d. to 8½d., the small reel runs to about 1½d., and the large to perhaps 3d. Few engineers have considered either the smallest "globe strain" or malleable iron safe to use, and have indulged in the larger sizes, in bronze, at from 1s. 10d. to 2s. 2d., or even 3s. The use of the larger reel, then, will reduce the usual cost per mile by from £8 to £16, and another small saving can be made on flexible suspensions by inserting the reels into special jaws cast on the brackets.

In order to simplify matters still further, and at the same time to increase the efficacy of the secondary insulation, a reel with more than one corrugation may be used, preferably one with three, and identical with that proposed above for the hanger. Under such conditions the whole insulation of a span would cost no more than 2s. 6d. to 3s.

Leakage and Electrolysis across Secondary Insulators.—Obviously leakage cannot take place across the primary insulator without the consent of the secondary, but luckily the converse is equally true, so that our main efforts should be given to rendering the primary leakage impossible, and the secondary will take care of itself.

There are samples of the four kinds of secondary insulators on the table, and all show clearly the electrolytic action noted as occurring on primary insulators.

That end of a "Brooklyn" or a "turnbuckle" or a "globe" which was attached to the pole—the negative side of that part of the circuit—can be identified by the collection of copper sulphate which has formed close up to the insulation. In the same way the zinc first and the steel next of the span-wire where it encircles the reel insulators falls a prey to the action, and gradually changes into a mass of oxide. Probably that was the prime cause of an accident caused by a live span-wire which recently cost a certain company some hundreds of pounds in the courts. So marked is this phenomenon after several years that a linesman may save himself time, and his employers money, by inspecting the secondary insulation first. If there is no deposit there is no leak, and

the primary insulation is good, and *vice versâ*. As a matter of fact we do not recommend this method of testing for everybody.

A peculiar instance of the beneficial effect of an accidental occurrence was noticed in connection with this question of electrolysis. Insulated turnbuckles are more liable than any other insulator to rapid deterioration, but on one line on which there were a great number they gave but little trouble. On that line the pole-straps were made too narrow to take the insulated end of the turnbuckle, so, contrary to custom, the metal eye was made negative. When used in the orthodox style, electrolytic action removes iron or brass from under the open end of the insulating material and splits it up as in the hanger, while turned the other way, with the insulator next the span-wire, the metallic ring or thimble is eroded and deposited over the negative surface of the insulating material and over the metal, but without any splitting taking place. For that reason it is better to use iron rather than brass, or the same troubles will arise as with brass hanger bolts.

That electrolysis is the cause, and not ordinary rust, is proved definitely by the specimens submitted, which are fairly representative of the bulk. Here are two turnbuckles which have been attached to the span-wire and pole in opposite directions. The leakage current left one at the insulated end, and in consequence the iron stalk is reduced from $\frac{1}{2}$ in. to $\frac{1}{4}$ in., and the insulation is spread out like a half-opened umbrella, but the stalk at the other end is reduced very little, and that quite evenly. On the other, the current left at the uninsulated end, and electrolysis has carried iron from the thimble or bush which passes through the centre of the insulation, over the length of insulation separating the thimble from the stalk, and has deposited it over the original galvanised surface, as may be seen by scraping off the layer of what is now oxide of iron. The quarry from which this deposited iron was hewn is plainly to be seen in the form of an irregular scar about 1 in. by $\frac{1}{2}$ in. by $\frac{1}{8}$ in. to $\frac{1}{4}$ in. deep, and the path taken by the metal can be traced by the "sign" of yellow rust. Except for a little surface rust the remainder of the turnbuckle is in excellent condition.

As we should expect, this action is much more rapid where there is only one insulator between trolley-wire and earth, or where the primary insulation is defective. For instance, the secondary insulation at certain types of section insulator deteriorates more quickly than those on the next poles, where there are ordinary hangers. The value of a section insulator can be assessed accurately by taking such observations.

One of the turnbuckles exhibited comes from a section-span, and is worse than its mate because the pole to which it was attached is bonded to the rail. The leakage paths were of unequal value, so the erosion or solution and the deposition were unequal.

Section insulators must be bad indeed when linesmen cannot work with safety when "protected" from the source of supply by 12 in series. Some are better than that!

Manchester uses triple insulation, but fate is pursuing her all the same. The end will be postponed, but it will come at last, as it will

come to all, unless the source of the trouble is stopped by keeping the primary insulation dry.

If the other types of secondary insulators are examined the characteristics of electrolysis will be found invariably. On brass "globe strains," copper salts at one end deposited over the original surface, and at the other reduced section and the insulation a little disturbed at the edges; on "Brooklyns" the same, and on reel insulators the galvanised span-wire in good condition everywhere but round about the best path for current to get to the pole, and there no galvanising and the steel disappearing.

No one who has such facts in his possession can hope that the insulators on the tramways of England, taken as a whole, can last fifteen years, unless steps are taken to prevent the dangerous leakage that goes on now. If those steps are taken there is no reason why every insulator should not last as long as the tramway, and all that need concern us then would be to put up the best and cheapest insulators to start with.

Trolley-wire and Trolley-wire Ears.—Until quite recently the general practice has been to use circular trolley-wire fastened to the supports by sweated ears. The ears have been either deep or shallow grooved, the former encircling the wire almost completely, and the latter only in part. Very few have refused to recognise that circular wire suspended in this way is unsatisfactory, but the fault lies with the ears and not with the wire. Many attempts have been made to overcome this difficulty with mechanical ears of various kinds, but without full success, although one of the samples shown (Rea and Reindorp) is the nearest approach to a solution which we have seen on the market.

The only problem involved is to provide an absolutely smooth and unbroken path for the trolley-wheel. If there is any change of section or gap in that path the wheel must jump, with the result that when no current is passing to the car the effect is identical with the effect of car-wheels at the joints of rails, and that when current is passing a more or less destructive arc is formed.

This trouble is the direct cause of the substitution of flexible suspensions for rigid suspensions on bracket-arms, for double insulation could be managed without the "bowstring." So long as the trolley-wheel runs with perfect smoothness, flexible suspensions have no particular advantage over rigid suspensions, if the trolley-wire is as taut as it ought to be. In fact, we suggest to this audience that economies may be made in this direction now that figure 8 and grooved wire have come into fashion.

There is no doubt of the efficacy of 8 wire in supplying the desideratum mentioned above, but the grooved section hardly does this, as the ears cannot be made to clear the trolley-wheels.* Nevertheless, the use of 8 wire is not extending in any marked degree. Two well-known firms of wire-drawers replied to an inquiry as to the ratio of 8 and grooved wire to circular wire supplied by them in the following terms:—

* *Electrical Review*, 1905, p. 211.

(1) "We cannot say exactly, but the proportion of figure 8 is very small, and we have been informed that this is being practically discarded in America, where it was very much used a few years ago."

(2) "The present ratio of demand for grooved is about 10 per cent. of the round, while figure 8 has practically ceased to be used according to our experience."

These makers state that the extra cost of grooved and 8 wire (weight for weight) is from £2 7s. to £3 per ton, but a large user of 8 wire writes that "there is no difference in the cost of wire, makers quoting us the same price per pound for each type." In any event, the difference in price is almost negligible, and might become so altogether if either section were used to the same extent that circular wire is now.

Then with regard to erection, a correspondent who has designed a complete line of fittings for both grooved and 8 wires, and has supplied large quantities of both, but has not carried out the erection, says: "The first cost of the fitting for the grooved wire is slightly more than the round, but not so much as in figure 8. It is very easily adjusted when up, and the wear on the fittings is practically nil. The wear of the wire is less than in the sweating system, as there is practically no under-running, and there is not the objection of having heated wire as in the sweating. . . . The objection to figure 8 wire is that it is more difficult to erect than the grooved wire, and more expensive in fittings, and in requiring more experienced men to fix it, but when properly fixed makes a very satisfactory job."

On the other hand, the user quoted above on price says that "there is no greater difficulty in erecting figure 8 than circular wire of similar sectional area, contractor's price for two recent contracts being the same per 100 yards for both. . . . One section . . . we have had working has given us no difficulty or trouble of any description," and he adds: ". . . in my opinion figure 8 is much better than grooved, one of the chief reasons being that the top lobe of the figure 8 allows a much better grip for ears than grooved wire, also *the bottom lobe, if you used, say, 2/0 section, can be made so that the contact area to the trolley-wheel is equivalent to 4/0 circular.*" The words in italics are pregnant with wisdom, as we shall see later.

The fact has to be faced that circular wire with the present forms of ear means continual expenditure for repairs and an unpleasant feeling that too much depends on the linesmen. Under these conditions—conditions which exist on 2,000 miles of tramway in this country—there are nearly 100 potentially weak points in every mile.

The use of some form of ear with circular wire, or of some special section of wire which will not give trolley-wheels a chance of bumping, removes those weak points at once, and the only question for those who do face the fact is "Which course is to be taken?"

Circular wire has been in use for so long, every one is so accustomed to it, that the majority of tramway engineers are chary of change, and it is possible that an ear may be found which will satisfy the essential condition, and not only render strange sections unneces-

sary for new work, but give a new lease of life to existing circular wire. We submit an ear for your criticism which we have some reason to believe fulfils the requirements, and as we have not protected it we do not hesitate to bring it before you in this manner. The great objection which we foresee will be raised against it is that it is a return to soldering just when every one is trying to make mechanical ears for circular wire successful. We have no new excuse to offer, and only venture to express an opinion that copper may be soldered to copper easily and cleanly without hurting the wire. Moreover, in every length of trolley-wire sold there are several points which have been heated for soldering after manufacture, and in this ear the soldered area is less than has been proposed before; but the area is quite enough, and the part soldered to the wire is made of copper tapered off to flexible ends, in order to overcome the tendency of ordinary shallow-grooved ears to part from the wire at each end because of their inability to

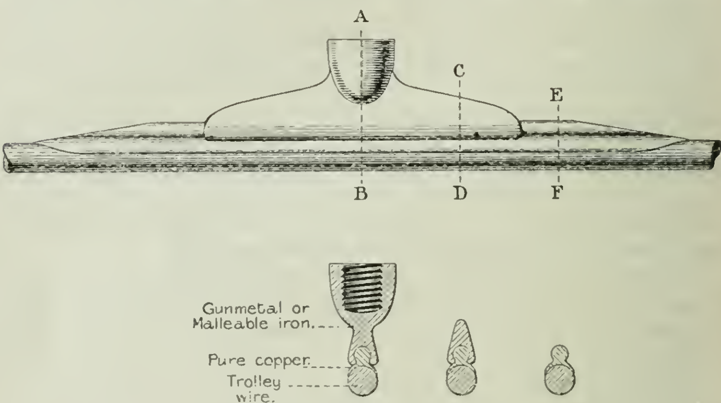


FIG. 1.—"Figure eight" Ear.

follow the small but frequent movements of the trolley-wire at the points of suspension. These ears put circular wire on the same plane as 8 wire (see Fig. 2, Pringle's ear, Appendix, p. 190).

Whatever ear giving these advantages is to be used, we think that it is better to continue the use of circular wire even though 8 be as cheap, as easy to erect, and as satisfactory in use. That is almost entirely because we do not consider that any other than circular wire can be quite as satisfactory in the long run.

Out of the forty-seven corporation tramways which answered Mr. McElroy's question as to the size of wire in use in 1904, fourteen use 1/0, four use 2/0, fifteen use 3/0, and seventeen use 4/0 S.W.G. circular wire. Three tramways using two sections are included twice.

In a few cases there is some difficulty in determining from the printed replies whether the sizes are given in B. & S. or S.W. gauge, and in view of the difference between the two clear distinction is desirable.

It is evident that the tendency in 1904 was towards heavier sections than the 1/0 which was almost a standard for several years, and during

the interval that tendency has become more strongly marked. In face of such a definite expression of opinion it will seem rashness on our part to suggest that the factors which have led to this radical change are not sufficiently clear.

Mr. Sayers says in the paper mentioned above that "there is no electrical necessity for using any wire larger than 0 S.W.G. . . . unless the traffic is extremely heavy," and in certain other special cases, as on curves of short radius. The average density of traffic is not what Mr. Sayers means by "extremely heavy," nor is it likely to become so. The necessity for heavy wire on the electrical count being removed, the mechanical count alone remains, and on this point every engineer has his own opinion, as it does not lend itself so readily to exact demonstration. Our opinion is that an equivalent section to 2/0 circular wire is the maximum required by the average tramway. The following table shows the relation between the four sizes in use :—

TABLE III.

S.W.G.	Diameter. Inch.	Area. Square Inch.	Breaking Strain. For 2 % to 3 % Elongation. Lbs.	Breaking Strain. For 4 % to 4½ % Elongation. Lbs.	Weight per Mile. Lbs.	Cost per Mile at 11d. per lb.
						£
4	0·400	0·12566	6,410	5,550	2,650	117
3	0·372	0·10868	5,870	4,790	2,220	101
2	0·348	0·09511	5,140	4,195	1,940	89
1	0·324	0·08244	4,620	3,635	1,680	77

Therefore those tramways using 4/0 have sunk £80 and £56 per mile more than they need if they had used 1/0 or 2/0 respectively; and those who have used 3/0 have sunk £48 and £24 extra. On the mileage of the seventeen and fifteen corporations only quoted above from Mr. McElroy's figures for the year 1904, the total capital sunk for no appreciable gain amounts approximately to :—

TABLE IV.

	Extra Cost Over 1/0.	Extra Cost Over 2/0.
	£	£
1. Tramways using 4/0 ...	30,000	21,000
2. ,, ,, 3/0 ...	9,600	4,800
Total	£39,600	£25,800

Those figures are startling when one reflects that they relate to trolley-wire alone, and to no more than forty-seven out of about three hundred tramways in the kingdom; and they should help to bring concretely before the minds of engineers that the choice of trolley-wire is not so much a matter of fashion as of present and ultimate economy.

There is a real need for larger contact area between trolley-wheel and wire than is possible with 1/0 or even 2/0 circular wire, and it may be that this need has helped engineers towards the use of 3/0 and 4/0 circular wire, but the same effect can be obtained in a cheaper way by rolling 1/0 or 2/0 wire to a flattened curve on the under side. Whether that is done with circular, 8, or grooved wire must rest with the individual engineers, and probably figure 8 and grooved wires are not feasible in such a size as 1/0.

We are the more insistent on the subject of returning to smaller sizes because the figures of wear which we give below show clearly that, points of suspension apart, No. 0 S.W.G. has a useful life which meets all present requirements.

Wear of Trolley Wire.—Trolley-wire wears from four causes :—

(1) Rolling friction due to trolley-wheels.
(2) Sliding friction due to trolley-wheels in fixed heads on curves and badly aligned wire.
(3) Arcing due to high-current density.
(4) Impure atmosphere.

Although circumstances have prevented the figures being complete, and although much remains to be done in this way by other and more competent observers, we think that the general statement above is fairly well borne out, and that there is some positive foundation for our conclusions :—

(1) That the depreciation due to rolling friction is almost negligible.
(2) That sliding friction may be reduced to the same negligible quantity by attention to alignment and by the universal use of swivel trolley heads of the freest type.
(3) That arcing is the most serious trouble of all, and must be discounted by the use of modified trolley-wire section and a complementary trolley-wheel.
(4) That the effect of an impure atmosphere requires further elucidation.
(5) That the method of suspension does not affect the wear, and
(6) That the effects of (*a*) height of wire and (*b*) pressure of trolley-wheel require careful examination.

In all the following tables the original diameter of the wire was 0·324″ maximum.

TABLE V.

Illustrating Conclusion 1.

Observation No. 1.—Line six years old. Level road. Single wire joining two wires at junction.

Diam. of single wire	0·312″
„ of double wires...	0·315″, 0·317″

Observation No. 2.—Same conditions. Another junction.

Diam. of single wire	0·302″
„ of double wires	0·310″, 0·3105″

(Nos. 1 and 2 together also illustrate Conclusion 6.)

Observation No. 3.—Line two years old. Level road.

Diam. of up wire	0·3185″
„ of down wire	0·3180″

Observation No. 4.—Line two years old. Level road.

Diam. of up wire	0·3205″
„ of down wire	0·3210″

(Nos. 3 and 4 together also illustrate Conclusion 6.)

Observation No. 5.—Line five years old. Level road.

Diam. of up wire	0·3095″, 0·310″
„ of down wire	0·311″, 0·3115″

(No. 5 also illustrates Conclusion 4.)

The small variation between the two wires under any one observation, and the remarkably small variation between the single wire and double wires at junctions where the former has taken twice the service of the latter, are good evidences for the conclusion that rolling friction has not much effect on the life of trolley-wire.

The results of Observations 1 and 2 are discrepant, perhaps, because in the second case the wires are lower than in the first.

Observations 3 and 4 are discrepant for the same reason.

Observation 5 was taken over a railway bridge, and it is thought that the somewhat large reduction for a level road is due to fumes from the engines.

TABLE VI.

Chiefly to illustrate Conclusion 3.

Observation No. 6.—Line five years old. Steep hill (1 in 12). Heavy cars.

Diam. of up wire	0·307″
„ of down wire	0·321″

Observation No. 7.—Line five years. Level road, but measurements taken at starting place.

Diam. of single wire	0·317″

Observation No. 8.—Line two years old. Slight hill.

Diam. of up wire	0·315″
„ of down wire	0·320″

Observation No. 9.—Same line. Level starting-place.

Outgoing wire ... ... 0·317″, 0·3175″
Incoming wire ... ... 0·322″

Observation No. 10.—Same conditions as 9, on another line five years old.

Outgoing wire ... ... 0·312″, 0·313″
Incoming wire ... ... 0·3175″, 0·318″

Observation No. 11.—Line two years old. Hill.

Up wire ... ... 0·3175″
Down wire ... ... 0·320″

Observation No. 12.—Line five years old. Hill (1 in 11).

Up wire ... ... 0·3075″, 0·3085″, 0·3080″
Down wire ... ... 0·320″, 0·320″, 0·319″

Observation No. 13.—Line five years old. Steep hill. Measurements taken at intervals of 40 yards.

Up wire ... ... 0·308″, 0·314″, 0·307″, 0·307″
Down wire ... 0·320″, 0·319″, 0·3175″, 0·3175″

Observation No. 14.—Line two years old. Steep hill. Wires higher than usual (21′ 6″ to 22′).

Up wire ... ... 0·319″, 0·3195″
Down wire ... ... 0·322″, 0·322″

(These results may be compared with 11.)

Observation No. 15.—Line four years old. Level. Both wires 0·3195″, 0·3205″.

Same line, steep hill.	Up wire	... 0·3105″, 0·311″
	Down wire	... 0·3205″, 0·320″
,, ,,	Up wire	... 0.3145″
	Down wire	... 0·319″
,, ,,	Up wire	... 0·314″, 0·313″
	Down wire	... 0·319″, 0·319″

These observations cover some 20 miles of route operated under divers conditions, and they seem to prove Conclusion 3 to the hilt. At the same time, taking a general view of the whole, it is probable that the first wear is rapid down to a certain point, both on up and down lines, and thereafter does not proceed at such a rate. That requires more substantiation than we are able to give at present, but the figures suggest that whether a line is two years old or six years old, the down wire has worn much the same.

Careful records kept from the beginning of traffic on a dozen lines scattered over the country are sadly needed.

TABLE VII.

To illustrate Conclusion 4.

Observation No. 16.—Line six years old. Hill by gasworks.

Up wire ... ... 0·3025″
Down wire ... ... 0·3095″

Observation No. 17.—Line two years old, in smoky atmosphere.

Up wire	0·316″
Down wire	0·320″

Observation 16 is not of great value by itself, but it may be compared with No. 13, where the hill is steeper and the traffic, if anything, heavier.

In such circumstances, we should look for the down wire to be smaller in No. 13 than in No. 16, but the reverse is the case, and the only reason we can suggest is that the atmosphere in No. 13 was comparatively pure. Moreover, an abnormal reduction in *both* wires of No. 16 is to be noticed. No. 17 is an example of a smoky atmosphere causing no apparent damage.

Table VIII.

To illustrate Conclusion 5.

Observation No. 18.—Line five years old. Level. Measurement taken—

(*a*) 3″ from end of ear at a rigid support ...	0·317″
(*b*) 6 ft. from end of ear at a rigid support ...	0·317″
(*c*) Half way between rigid and flexible suspensions...	0·315″
(*d*) 6 ft. from flexible suspension	0·317″
(*e*) 3″ from flexible suspension	0·317″

Observation No. 19.—Line five years old. Hill, span-wire construction. Measurements taken—

(*a*) 4″ from ear	Up	0·308″	down	0·320″
(*b*) Midway between ears...	„	0·307″	„	0·322″
(*c*) 4″ from next ear ...	„	0·3085″	„	0·320″

These seem to illustrate Conclusion 5, that the method of suspension does not matter, but more proof is needed to settle that conclusively.

Table IX.

Observation No. 20.—Wires held rigidly by ears at short distances apart under bridge. 11′ 3″ clearance between wire and rail. Usual clearance beyond bridge. Measurements taken on—

(*a*) One wire under bridge ...	0·322″, 0·320″, 0·318″, 0·318″
(*b*) Same wire clear of bridge...	0·319″, 0·320″
(*c*) Other wire under bridge ...	0·315″, 0·316″, 0·316″, 0·316″
(*d*) Same wire clear of bridge...	0·318″, 0·317″

Observation No. 21.—Line five years old. *Wires very slack.*

Observation No. 22.—Same line as 21. Steep hill, span-wire construction. Wires fairly tight.

(*a*) 6″ from ear ...	Up	wire	0·308″,	down	wire	0·320″
(*b*) Centre of span ...	„	„	0·307″	„	„	0·322″
(*c*) 6″ from next ear...	„	„	0·3085″	„	„	0·320″

Here we have three seemingly conflicting results.

In the first place, Observation 20 demonstrates that the wear is independent of the height of the trolley-wire under peculiarly harsh circumstances.

Secondly, Observation 21 points to a much slighter difference in height, causing variations in diameter ; and last, there is Observation 22, in which the results on the up wire are directly contradictory of No. 21, while the down wire is in agreement with it.

We do not advance any explanation of the first contradiction, but suggest that the second is due to the fact that at the point farthest from the points of suspension of a wire which is passing current to a car, the contact pressure of the trolley-wheel must be less whenever it lifts the slack wire above the points of suspension ; but the whole subject merits extended and patient observation by some one who will not try to make figures fit theories.

APPENDIX.

Poles.

Table No. X. gives some idea of the variation in American practice.

Table X.*

Name of Town.	Trolley Wire.	Poles.	
Baltimore ...	o and oo round	5″ × 4″	—
Boston	oo ,,	$6\frac{1}{2} \times 5\frac{1}{2} \times 4\frac{1}{2}$	750 lbs.
Buffalo	oo ,,	—	—
Chicago ...	oo ,,	7 × 6 × 5	900 ,,
Cleveland ...	oo ,,	7 × 6 × 5	625 ,,
Denver	o ,,	—	—
Detroit	oo ,,	—	675 ,,
Indianopolis ...	oo ,,	—	600 ,,
Milwaukee ...	ooo figure 8	8″ × 7″	850 ,,
Philadelphia ...	oo round	8 × 7 × 5	915 ,,
Pittsburg ...	oo ,,	—	—
San Francisco...	All kinds	7 × 6 × 5	—
St. Louis ...	oo round	6 × 5	545 ,,
Minneapolis ...	oo figure 8	—	—

* Abstracted from *Street Railway Journal*, August 29, 1903.

It may be assumed without much chance of error that all the American lines quoted are built on the span-wire system, in which case the *lightest* poles (*i.e.*, those used for straight-line work) might be of the same weight always, but the weights vary from 545 lbs. in St. Louis to 900 in Chicago and 915 in Philadelphia, although the section of trolley wire is the same in all cases.

Owing to the prevalence of single-deck cars in the United States, poles are rather shorter than ours, probably averaging 29′, which accounts in some degree for their lightness as compared with British poles; but these remarks are intended chiefly to draw attention to the extraordinary and apparently meaningless difference in the weights, even in the professed home of standardisation.

Coming back to England, the following three instances are hot from the press :—

Falkirk.

Bracket arms : 8′ to 16′.

Poles :	Light	1,000 lbs.
	Medium	1,000 „
	Heavy	1,230 „
	Extra Heavy	1,400 „
Wire :	3/o. No centre poles.	

Dartford.

Spans, and brackets up to 16′.

Poles :	No centre poles.	
	3 sections, 31′ long.	
	Light	900 lbs.
	Heavy	1,500 „
Wire :	2/o B and S′.	

Mansfield.

Brackets : 12′ to 16′.

Poles :	Light	840 lbs.
	Medium	960 „
	Heavy	1,168 „
Wire :	2/o S.W.G.	

Rake.—In Sydney the practice on 42′ roads is to plant poles 6′ deep in about $\frac{1}{3}$ yard of concrete only, with 6″ rake, the soil being ordinary. From $1\frac{1}{2}$″ to 2″ of the rake is left after the span has been pulled up.

Rusting.—The deterioration of the outer surface of that part of the pole which is buried is negligible; while the general opinion seems to be that in many cases the part hidden by the base is not affected seriously, the authors have seen plenty of evidence to the contrary. Probably it depends very much on the design of base, the manner in which the joint is made, and other special circumstances, and no definite universal statement can be made.

Flexibility is a more valuable attribute in a pole than many people think. It is, in fact, the spring of the pole which provides any flexibility that there is in the usual short bow-string suspension tightly stretched, and a great deal of it in the case of the, as usual, taut span. Almost certainly the long life of the trolley wire on the Dickinson side-arm system was due to the extreme flexibility of the little taper poles, for the mechanical ears were as crude as one might expect of the time. Not long ago the same ear was suspended rigidly to much stiffer poles, and the trolley wire began to suffer immediately at the ends of each ear.

A comparison between the poles of the West Bromwich Corporation lines and of the South Staffordshire and Kidderminster lines is a comparison of extremes, but is instructive. Somewhere between these limits lie all other British poles.

TABLE XI.

West Bromwich.	O/D of Sections.	Weights in lbs.	Weights of Bases.	Weights of Finials.	Pair of Collars.	Total Weight per Pole.
Light	$11'' \times 8\frac{1}{2}'' \times 7''$	1,624	378	89	56	2,147
Centre	$10'' \times 5\frac{1}{2}'' \times 7''$	1,324	662	89	56	2,131
Anchor	$13\frac{1}{8}'' \times 11\frac{1}{2}'' \times 10''$	2,464	588	140	42	3,234

TABLE XII.

South Staffordshire.	Outside Diameter and Section.	Weight.
Ordinary bracket ...	$6'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ steel tapered	448
Heavy bracket ...	$7'' \times 3\frac{3}{4}'' \times \frac{1}{4}''$,, ,,	560
	No collars and few bases	

The weight of metal per mile of West Bromwich line, excluding bracket arms and scroll-work, is as follows:—

Span-wire construction ... ... 84 tons.
Centre-pole ,, ... 49 ,,
Bracket ,, ... 42 ,,

while one mile of bracket-arm construction on the old South Staffordshire lines weighed between 10 and 11 tons.

Bases.

It is worthy of note that at Falkirk, except on those poles which support arc lamps, there are no bases.

We have verified the extraordinary pitting on the pavement side of the pole only, caused by dogs, on the old South Staffordshire line where no bases are used.

One pole, which had been placed on a mid-street refuge, was attacked all round. It appears that the effective range of the mean dog is no more than 6″ to 8″.

Money is not spent on bases in America, but in Philadelphia "the poles have a sleeve which fits over them at the ground-line to protect them against rust at that point" (the American dog is in too much of a hurry to stop); and "on the Chicago Union lines a cast-iron sleeve, fitting loosely, is put at the ground-line, pitch being poured between sleeve and pole" (*Street Railway Journal*, August, 1900).

In Sydney the corrosion trouble, whether due to the elements or to dogs, is overcome by wrapping a sheet of pure zinc about 18″ long round the pole so that 3″ is below and the rest above ground.

Span Wire.

A writer in the *Electrical Review* (March 30, 1906) has suggested that span wires should be made up in the shops from measurements made at each pair of poles, and that the nozzles could be treated then by the sheradising process of galvanising, "which consists in burying the parts to be coated in a mass of zinc powder and heating to 500° F." In this way any rough treatment of the original coating by the workman's pliers can be made good, and so long as bronze hangers are not used, the life of the span wire should be lengthened.

Doubtless suitable arrangements could be devised to enable the process to be carried out on the road if there are difficulties about completing all spans in the shops.

Insulators.

Hangers.—Even before 1903 un-insulated hangers were used in Milwaukee, double insulation being obtained by means of four strain insulators.

Working on the suggestion contained in the first portion of this paper, Mr. Hartley, of the South Staffordshire Tramways (Lessee) Co., has designed a hanger in which the insulating material is porcelain.

The insulation resistance of an overhead hanger was tested under various conditions to show what may be expected from the use of the hanger shield as a means of protecting the bolt from the effects of water carrying metallic dust, etc., thrown off the trolley wheels of passing cars, and from the electrolytic corrosion consequent upon leakage so produced.

1. New bolt in hanger—

	Insulation Resistance.
(*a*) Dry	Infinity.
(*b*) Wet*	Infinity.

2. Old bolt in old hanger as removed from the line without selection—

	Insulation Resistance.
(*a*) Dry	2,267 megohms.
(*b*) Wet	0·005 megohms.
(*c*) Bolt scraped clean and moisture removed by wiping only ...	330 megohms.
(*d*) Bolt in same condition as (*c*), but dried by stoving for 44 hours at 160° F.	Infinity.
(*e*) Bolt in same condition as (*c*), but tested after being dipped in water and not dried	5·32 megohms.

Then, as showing the dangerously deceptive appearance of bronze insulated bolts which have been exposed to electrolytic action for some time, further tests were made on (*a*) an iron bolt in the penultimate stage of dissolution, in which the insulation had split and opened outwards like an umbrella; (*b*) a pair of bronze bolts which looked no more than dirty. All were in their casings just as they were removed from the line, and were held over saturated steam for a minute or two, and allowed to stand fifteen minutes before applying the testing pressure of 500 volts. The insulation resistance of each was—

(*a*)	0·45 megohms.
(*b*)	{ 0·06 megohms. 0·086 megohms.

At St. Helens insulated hangers have given much trouble from corrosion of the iron part of the bolts, and this is the case equally when they are supporting trolley wire or bare feeder wire under which trolley wheels do not run, but it is probable that the greater part of the trouble in this case arises from the peculiar atmosphere of the district.

The engineer (Mr. E. M. Hollingsworth) informs us that the two bolts which are exhibited were in use about eighteen months. Primary and secondary insulators alike are affected in this manner, and all qualities of insulation suffer equally. Brass bolts had to be abandoned because many fractured, and painting has been tried without avail.

Trolley Wire.

Safety.—Further testimony to the safety of overhead tramway construction may be found in the report of an interview with the

* This bolt did not remain wet in reality, as the water ran off the new surface just as if it were covered with an oily film.

General Manager of the Manchester Corporation Tramways Department, which appeared in the *Tramway and Railway World* for March 8, 1906, in the course of which he says: "I do not think we have had more than six breakages altogether over the entire system since we started in 1901. . . . There has been no serious accident due to falling wires."

Figure 8 Wire.—Amsterdam uses on its lately constructed tramways figure 8 wire of a flattened section.

In an article in the *Street Railway Journal*, August, 1900, on the general features of modern construction the writer says that figure 8 wire has "not met with favour in the majority of places," and seems to think that this is because specially trained linesmen are required to put it up properly. Where it has been adopted the quality of the construction is good.

The experience in Sydney (*Electrical Review*, January 23, 1906) is that even figure 8 wire is bumped to death at ears when speeds are high—20 to 30 m.p.h.—but the same observer says that for the speeds more usual in England this wire is very suitable, and is more easily maintained than round wire.

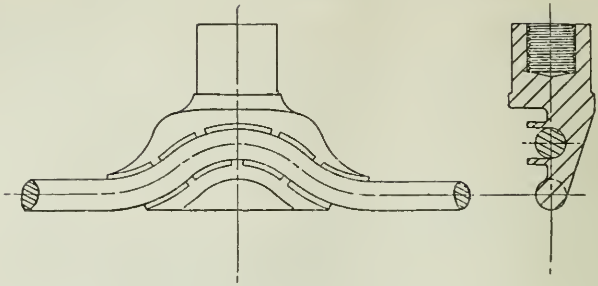
To those who fight shy of figure 8 wire because of its tendency to turn over we would say that it is not possible without the aid of tools to turn this wire on its side at any part of a 40-yard span. Wherever figure 8 wire is turned over it is due to a twist being put into it during erection. Like most of the troubles in connection with figure 8 wire, this, too, is due to carelessness or to insufficient training.

Ears.

For Circular or Oval Wire.—Additional reason for not giving up the most convenient section is to be seen in the "loop" ear by Pringle, an advance on the "Rea and Reindorp" ear to which reference is made on page 176. This ear provides as perfect a run for the trolley wheel as can be obtained if soldering is to be avoided. It is, moreover, made of pure cast copper, by the use of which the arcing wear may be reduced (Fig. 2).

To those who think that the quarter of a million soldered ears of more or less defective patterns which are in use in England, taken together with the small number of trolley wire breaks of all kinds during the last ten years, and the infinitesimal number traceable to abuse of the soldering-bit, are no bad testimonial to the sufficient skill of the linesmen in this work, the "figure 8 ear" exhibited will appeal as something which provides no suspicion of an obstacle to the oldest trolley wheel; while the test made by Mr. Browne to illustrate convincingly our point that the adhesiveness of an ear soldered to rather less than half the circumference of circular wire is more than enough for all practical purposes, will dispel any doubts that may have lingered.

Ears for Grooved Wire.—In face of the sample lent by Mr. C. W. Hill, Electrical Engineer of the Birmingham Corporation Tramways, the statement on page 178 that grooved ears cannot be made to clear



PRINGLE'S COPPER LOOP EAR.

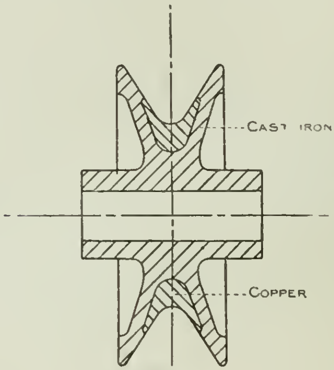
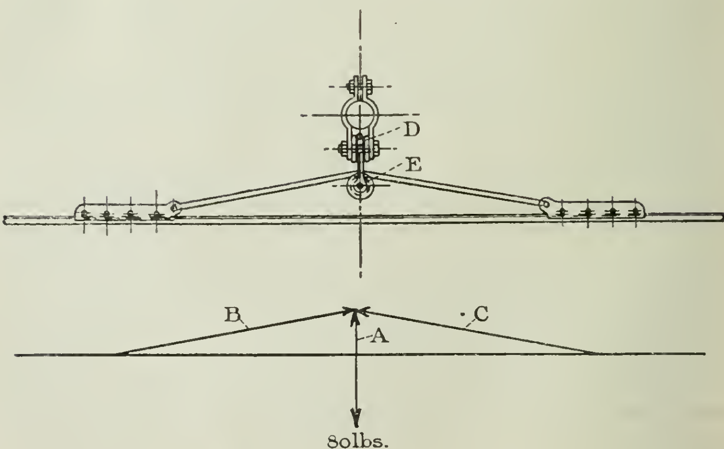


FIG. 2.



PRINGLE'S TANGENTIAL SUSPENSION.

FIG. 3.

trolley wheels must be withdrawn, and we do so gladly, being very pleased to mark progress in this direction. This car, and one or two others which we have seen, certainly present no obstacle at all to the free passage of trolley wheels.

Tangential Suspension.—This is a novel form of suspension proposed by Mr. Pringle. A model is exhibited, but is on too small a scale to demonstrate properly the advantages claimed for the system (Fig. 3).

Briefly these are :—

1. Considerable flexibility in all directions in the neighbourhood of the supports, tending to lessen the deterioration of the trolley wire and of ears of the fouling pattern.
2. Elimination of the "trap" formed by the bow-string suspension.
3. The angle of all bends in the trolley wire due to pull-offs will be halved, giving easier running.
4. Cheaper construction.

The idea is that the tangential supports alter the direction and distribution of the stresses in such a manner as to enable the ordinary pressure of the trolley to lift the wire even at the points of support, and one of the authors can testify that this does happen, to the extent of 1″–2″ in actual practice, with 3/0 wire.

Conclusion.

In conclusion, we would say that, however erroneous may be our observations and our deductions, however far-fetched and inopportune our suggestions and our strictures, we have the satisfaction to know that this paper has been written as the indirect result of practical experience, gained since the year in which electric traction made a substantial start, and as the direct result of several months' labour and thought. We submit it to your criticism as an earnest attempt to ventilate the question of lowering capital expenditure.

Our best thanks are due to the following firms for courteous replies to inquiries :—Messrs. S. Dixon & Son, R. W. Blackwell & Co., Estler Bros., W. F. Dennis & Co., John Spencer, Ltd., Jas. Russell & Sons, and A. Dickinson & Co., consulting engineers ; also to R. F. Browne, Esq., of the Birmingham and Midland Tramways Joint Committee, who has taken much trouble in supplying us with information out of his experience, and to Messrs. H. J. Wightwick and D. C. Henderson for kindly testing samples.

Discussion at Birmingham, February 14, 1906.

Mr. Henry M. Sayers (London) (*communicated*) : The paper is of a rare and valuable class, giving the experience of men who are in direct contact with the works described. Such experience forms the best basis for improvement and the promotion of the highest economy. Mr. Sayers.

I sympathise with the authors in their attack on needless expenditure

Mr. Sayers. in overhead construction. They know the influences that make against economy, and that it is not primarily to engineers that these arguments should be addressed.

I suggest that every specification for overhead work should provide that no two metals galvanically different should be in contact, as I am convinced that this is right in principle. The use of bronze insulated bolts is, however, strongly resisted by contractors, and, in fact, the breakages of the screwed ends are excessive.

Iron or steel bolts deteriorate very badly just above the ears, and also rust upwards and under the insulation, as observed by the authors. I find it hard to understand the authors' statements as regards the difficulties experienced with bronze bolts. Electrolysis will no doubt lead to a metallic deposit advancing from the edge of the hanger bolt socket towards the line surface of the bolt. But this presupposes some solvent of the metal and a strong solution, since weak solution and high pressure lead to the evolution of much gas and the formation of a loose non-coherent metal paste of high resistance. It does not seem that the somewhat more rapid oxidation of the deposited iron can come into play, since so long as the line is alive it will be negative to the electrolyte, and much mingled with hydrogen. I have seen many iron bolts that have failed in bad atmospheres, yielding iron sulphate, but believe that the breakdown is generally due to charring of the insulator surface. Hence, if shellac and other organic messes are discarded, and hanger bolts insulated with porcelain reels strung in the span wire as suggested, the most serious trouble with overhead work would disappear. Perhaps the authors can suggest some further clue to the trouble. The invention of the splash-guard seems a brilliant notion, but accumulation of dust and spiders' webs above the shield will need attention. I do not agree with the advocacy of slack wiring. It is mechanically wrong, just as are slack tension bars in a bridge truss. But overhead work may be overstrained, especially when put up in the summer. I dealt with the matter of wiring tension, and partly with the cause of wear of ears, in my Tramway and Light Railway Association paper last year. I think that the authors' figures and examples do not entirely justify their explanations. I suggest that what is wanted in an ideal trolley wire is uniform vertical rigidity, and any departure from uniformity must result in local wear.

Mr. Yerbury. Mr. H. E. Yerbury (Sheffield) (*communicated*): I am strongly impressed with the desirability of placing all telephone and Post-Office wires underground. In Sheffield this has been done in several instances, the Corporation as a rule bearing approximately half the expense. I think that the poles in any section should be kept as nearly as possible of one diameter, the thickness being varied according to the strains. To dispense with the base will shorten the life of the pole. In Sheffield we paint the poles once a year, and raise all bases and collars, which is a simple matter when only a thin film of mastic cement is used at the joint. In some parts of our system the atmospheric conditions are very bad, and we found it economical to use phosphor bronze or copper span and guard wires, as galvanised material does not last longer than

about three years. We have discarded ordinary hanger bolts, as the rust splits the insulating material, and use either galvanised or sheradised insulated bolts, which last several years longer. In my opinion porcelain reels are entirely satisfactory on pole-straps or flexible suspensions. I do not agree that flexible suspensions have no advantages over rigid suspensions. With a 1–2 mt. car service there is always a certain amount of "see-saw" action, and it is better for the ear to assume the same angle as the wire than to remain in a horizontal position. I approve of deep-grooved ears, unsweated, and if of correct shape and properly clamped, there should be no sparking. In Sheffield we have discarded soldered ears for about five years, with gratifying results. Mr. Yerbury.

Figure 8 wire is desirable where wall rosettes are used, as it is less noisy than ordinary wire. I am surprised that no mention has been made of either phosphor bronze or "Phono" trolley wire. We have had both materials in use about four years with good results, the only drawback being the comparatively high resistance. I cannot agree that arcing is the most serious trouble, as there should be no signs of it with an efficient system. From my experience the method of suspension does affect the wear and consequent life of the overhead line, but, as is well-known, careful adjustments and maintenance of trolley standards, heads, and wheels, lengthens the life of an overhead equipment very materially.

Mr. HENRY MOZLEY (Burnley) (*communicated*): The subject treated by the authors has received very little attention hitherto. I have long been dissatisfied with the extravagance in construction visible on all hands, and improvements in this direction will enable many a branch line to be opened on which at present there is no prospect of meeting capital charges. It cannot be too firmly impressed on the minds of tramway managers that nothing is too small to save, and because the cost of overhead construction appears a small proportion of the whole cost of the undertaking, it is no reason why the small savings clearly shown in the paper should not be carefully studied and acted upon. Mr. Mozley.

Mr. HENRY LEA: From an æsthetic point of view it is not desirable either to lighten the poles or to do away with the bases and collars. Do the authors propose to reduce the poles below the sizes recommended by the British Standards Committee? These sizes are the result of very careful investigation, and, I think, should be accepted. The authors have referred to the use of brass bolts. This is about the last material that should be used in damp situations. Mr. Lea.

Why do we go on using a system which needs such a collection of perishable articles? In the Lorain system in use at Wolverhampton there is nothing to be seen above the surface. There is a remarkable freedom from breakdown, and the system does not suffer from the many troubles referred to by the authors in connection with the overhead system. I believe that it is now being run at a lower cost per car mile than any other tramway of the same size in the country.

Mr. C. W. HILL: It may interest those connected with tramways to learn that a new point has been recently raised in connection with Mr. Hill.

Mr. Hill. guard wires. It is suggested that they may not be at the same potential as the wires they are supposed to protect, since the latter may be connected with earth in a certain position near the rails, where the potential is higher or lower than at the point where the guard wire is bonded to the rails, the difference being anything up to the Board of Trade limit of 7 volts. It is claimed that this effect is likely to give false instrument readings, and so far as railways are concerned, it might be the cause of accidents. It is an interesting point, and may assist in the general disuse of guard wires.

With regard to the Standard Committee's poles, I have found from actual load tests within the specified limits that all the deflection takes place in the bottom section. The top and middle sections, being only $\frac{1}{4}''$ thick, are not too strong, and one must conclude that the bottom section is at fault.

The strength of poles for span-wire work must be determined by the size of the trolley wire, the weight of proposed fittings, and the required span. Stronger poles must be used for nice, trim, taut spans than for slack, sloppy spans. I do not, however, advocate the use of spans pulled up so tight as to destroy the advantages derived from flexible suspension.

The detrimental effects on the life of the poles due to bases can be overcome by a liberal use of Dr. Angus Smith's compound, by coning the concrete at the ground level, and by properly caulking round the top of the base.

With reference to fittings, I have found gun metal perfectly satisfactory where properly galvanised span wires are used, and in any case the authors' remarks only apply to straight line hangers, as I assume galvanised thimbles are now used on all new work. I believe the grooved circular trolley wire will prove more satisfactory than the figure 8 section, provided well-designed ears are used. As far as the size is concerned, the use of heavier gauges than formerly is due to the inability of the small sizes to stand the wear and tear of heavy city lines. The authors have not taken into account that in a certain degree the more copper you have in the overhead line the less is the amount required underground. My experience is that the greater the rigidity of the suspension, the greater the wear due to increased arcing and hammering. Breakages at the ears are also more frequent. I am also convinced that too much tension on trolley pole springs increases the arcing and hammering to a considerable degree.

The paper gives results of the wear of wire under a particularly low bridge where the pole tension must be excessive, but I do not think that this proves that the extra tension does not affect the wear of the wire, because the cars go very slowly under the bridge, and the wire, being suspended at such frequent intervals in the troughing, is practically a rigid rod, and the only wear taking place is that due to rolling friction.

Mr. Browne. Mr. R. F. BROWNE: The authors' observations on the causes of failure and weakness of overhead material are distinctly practical, and in my opinion their theory will be difficult to refute. Within the last

two years I have erected and tested several types of pole similar to those referred to in the paper. A pole 31′ long, $7\frac{5}{8}'' \times 0{\cdot}4''$, $6\frac{5}{8}'' \times 0{\cdot}31''$, and $5\frac{5}{8}'' \times 0{\cdot}26''$, weighing 840 lbs., is, I believe, the second pole mentioned. Tested in the usual manner these poles gave a $5\frac{7}{8}''$ temporary deflection with a 500 lbs. pull, and $\frac{1}{2}''$ permanent deflection with 1,000 lbs. A taper pole 31′ long, $6\frac{1}{2}'' \times 0{\cdot}437''$ to $4\frac{1}{2}'' \times 0{\cdot}437''$, weighing 865 lbs., deflected $3\frac{3}{4}''$, with 500 lbs., and showed a permanent set of $\frac{3}{16}''$ with 1,000 lbs. The Standards Committee medium pole, $8\frac{5}{8}'' \times 0{\cdot}343''$, $7\frac{1}{2}'' \times 0{\cdot}31''$, and $6\frac{1}{2}'' \times 0{\cdot}25''$, weighed 875 lbs. The temporary deflection with 1,250 lbs. was $5\frac{3}{8}''$, and with 1,750 lbs. the permanent deflection was $\frac{3}{4}''$. Although the weights of these poles only vary slightly, there is a good deal of difference in the strength. In comparing weights it must be remembered that a three-joint pole may easily weigh more than a corresponding taper pole, owing to the telescopic joints. The cost of taper poles is considerably more than three-joint poles of similar strength. The suggestion that a 2″ rake is enough for a pole before any strain is put on depends entirely upon the strength of the pole. I agree with the authors' remarks about concrete, and suggest that there are many poles in this country standing up to their work which have been erected with practically no cement in the concrete. I see no reason why poles cannot be erected with lime concrete, in maiden ground, except possibly anchor and pull-off poles. The authors' remarks on secondary insulation are much to the point. I believe in pot reel insulators, and have had some tested, of the same type as those mentioned, which broke with a strain of 2,200 lbs. I now use a larger size, which I have no doubt will not fail under 2 tons. A great point in favour of these insulators is that if they fail electrically they have already failed mechanically, and this failure can be seen from the road without difficulty. They are also more easily replaced than other types, and require no re-nozzling. I favour "figure 8" section wire. An advantage not mentioned in the paper is that anchoring and splicing can be done without bending the wire. A small portion of the top lobe of the wire is cut out, and one side of the ear or switch has a projection or boss which fits into this recess. This gives a level surface for trolley wheels to pass under. Mr. Browne.

Mr. P. J. PRINGLE (Burton-on-Trent) (*communicated*) : Many of the authors' observations are original and of great importance as concerning the life of tramway undertakings. I agree with them as to the cause of the deterioration of hanger bolts. I have recently closely examined the overhead work in Burton-on-Trent, which has been erected $2\frac{1}{2}$ years, and have found decided evidences of bolt deterioration. One can only assume that managers have, up to the present, looked upon this question as an inherent necessity, and as it is a gradual process, a few breaking down from time to time, it has not been given the importance it deserves. I believe that the shield introduced by the authors will remove the cause of the trouble, and I am having these fitted in all extensions and renewals. I suggest that the authors modify the shield so that it can be fitted on to existing hangers without removing the bolts. It would pay most tramway Mr. Pringle.

Mr. Pringle. systems to attach such shields. I cannot agree with the recent contributor to the *Electrical Review* who contends, in opposition to Mr. Tweedy, that the wear on ears and trolley wires is mainly mechanical and not due to arcing, neither is the type of ear there illustrated any improvement, since it still retains the objectionable feature of forcing the trolley wheel to take up a new position on advancing over an ear, which must result in hammering and vibration. On a hill with a maximum gradient of 1 in $11\frac{1}{2}$ I have had to replace some of the ears on the up line, which are the ordinary deep groove pattern with 3/0 circular wire, in about $1\frac{1}{2}$ to 2 years. I find the wear on the up line trolley wire in the vertical plane 5 to 6 mils more than on the down line. The side wear on the trolley wire towards the end of the ears, owing to the rapid wearing of the ear, is in some cases as much as 25 mils. No mention has been made of the greatly reduced conductivity of the ear compared with the trolley wire, and this, coupled with the reduced contact surface between the wheel and the ordinary ear, causes the pitting appearing on ears, which is very marked on up grades, the trolley wire on the same line showing no such appearance. I agree that grooved wire is very little improvement on circular wire. To obtain the longest life of one's overhead system, the trolley wheel must have a path as even in every way at the points of support as it has on the trolley wire itself, and if this cannot otherwise be obtained recourse must then be made to figure 8 wire. I am afraid that it is frequently the passage of a new trolley wheel along an ear of any particular design or finish which is considered. If, instead of the new wheel, one nearing the end of its life were considered, the amount of obstruction that it has to meet on passing over an ear may come as a considerable surprise to some. It should always be insisted upon that a trolley wheel have the sides of the V groove turned down at a period of half its life.

Mr. Prosser. Mr. H. R. Prosser: It is not solely the question of what load a pole has to carry, or the rake with which it is set, that has to be considered, but also its rigidity when loaded and under strain. The South Staffordshire poles are strong enough to carry all necessary strains, but are far too resilient when the cars are passing, and this causes that hammering and sparking which gives so much trouble. Ornamentation does not add to the strength of a pole, but certainly adds to the finish and general appearance. Bases protect the most important part of a pole, viz., that at the ground line, where all destruction commences, and continues more rapidly than at any other part of the pole. I cannot believe in the arrangement of soldering a piece of "figure 8" section wire to the top of the trolley wire and to the underside of a clip, when a proper mechanical clip would do away with all the difficulties spoken of. Owing to oscillation, trolley wheels do not wear to the radius of the wire, but to a larger radius, and so are able to accommodate their travel along the clips. I cannot understand the authors' statement that the lower surface of the wire at the clip is not touched by the trolley wheel, especially as they showed worn clips having an undulated surface on the bottom or running side

of the clip. How would the soldered wire method stand the extra strains caused by curves or changes of grade? Mr. Prosser.

Mr. H. HARTLEY: I agree with the authors that in many instances poles and bases could be reduced in weight and cost without sacrificing safety or durability. The South Staffordshire poles have been instanced as light poles. The larger size, $7'' \times 3\frac{3}{4}'' \times \frac{1}{4}''$, have in some cases bracket arms 10 to 11 ft. long carrying two wires. They have been in service thirteen years, and are still in excellent condition except for a little corrosion on the ground line. They would not be suitable for span-wire work, but would surely be strong enough as centre poles with arms, say, 6 to 8 ft. long. Bases do protect the pole, and it would be a mistake to dispense with them. I have found no rust inside, in cases where the poles have been in service three to four years. By raising the concrete a little above the ground line, moisture would drain off, and there should be no sweating. Mr. Hartley.

The old South Staffordshire poles have no bases, but simply a small collar at the ground line. They show undoubted signs of corrosion, but on one side only (the footpath side). The subject of malleable iron *versus* gun-metal fittings is a very debatable one. My experience bears out that of the authors as to the local action which takes place between gun metal and the galvanised span wire. Although this does not take place with malleable fittings, these do not (at least in my district) give any advantage over gun metal, however they are painted. Malleable fittings are generally machined after being galvanised, and it is at the junction of the machined portion and the galvanising that it commences to peel off. The best insulator I know of is the bell shaped, with the bolt moulded into the insulating material. I know some in service now that have been in use since 1892. Electrolytic action takes place as in other types, but they are more easily cleaned. Porcelain is the best material for secondary insulation, and I see no reason why it should not be used for primary insulation. Such insulators are cheap, and if designed to suit a malleable iron hanger, galvanised but not machined, local action would not occur as it does with gun metal. I have had experience with practically every type of ear, and consider the mechanical type the best. Hammering action, resulting in a certain amount of sparking or arcing, occurs with either mechanical or soldered ears. It is most marked on solid construction or short bowstrings, even when the trolley tension is cut down to a minimum. I have had a short experience with "figure 8" wire, and it has given every satisfaction. We obtain smooth running and no wear on the ears. As regards the wear on trolley wires, I think that in some cases there is more wear on the up wire, and in other cases the reverse. The trolley wire on the old South Staffordshire system was originally 0·34" diameter, and the maximum reduction due to wear that I have been able to trace is 0·015". This figure does not, of course, refer to the wear at the ear, which is much greater. I do not think that the new soldered type of ear, which the authors have shown to the meeting, will suspend the wire efficiently.

Mr. Fourniss. Mr. C. W. FOURNISS: I agree that for ordinary work a saving could be effected in the weight of poles. Those used for anchor and pull-off work, however, are frequently too light, and give way at the first joint. The rake of a pole does not altogether depend upon the strength of the pole, but to a larger degree on the nature of the ground. The small rake of 2″ mentioned in the paper is not visible from the ground. For all practical purposes bases are unnecessary, but in my dealings with local authorities I have always found a decided objection to such a suggestion. I understand the authors that the objection to collars is that they hold water. I would suggest that in their place a small clamp be used, which would fit the hole tightly and prevent the accumulation of water. On the line with which I am connected we use two kinds of pillars, one filled with bitumen and the other finished off with concrete. The former give no trouble, and when inspected the whole pillar is found perfectly dry. The latter type is a continual source of trouble, water collecting in nearly every box on the route. I find that a very small percentage of insulated bolts fail, and that such failures are due to a very strong side strain. As regards secondary insulation, we have decided to discontinue the use of Brooklyn and Globe strains, as we find porcelain insulators quite suitable. Was the authors' suggestion that reel insulators be placed horizontally, with the downward strain on the flange, the result of actual experience? I agree that 2/0 wire is sufficient for a line with a five-minute service, but with a more frequent service a larger wire is absolutely necessary, and in such cases the extra capital cost does not assume any great importance. There are two reasons for wear of trolley wire in addition to those mentioned by the authors—the speed of the cars and the nature of the trolley wheels and wire. Poor or hard metal in the wheels soon causes appreciable wear. My experience has been that rolling friction has a great deal to do with depreciation, and also that the method of suspension does affect the wear to a great degree. I have personally measured several sections of trolley wire which have been erected two and a half years and which have been in actual service fourteen months. Forty-eight measurements were taken on hills of varying gradient, in twenty cases the "up" and in twenty-eight cases the "down" wire having worn more than the other. The most interesting discovery was that the wire wears taper from ear to ear, getting smaller in the direction of running, the wear at the centre of the span being approximately a mean between the wear at either end. The only reason to which I can assign this peculiarity is that the vibration set up in the trolley wire, when high-speed cars are running under, affects the upward pressure, and consequently the area of contact. I find that wear on central under-running work is much less than on side bracket work. I would like to ask the authors if they have noticed the peculiar "U" shaped corrugations which appear in close proximity to the ear, these corrugations getting smaller and smaller as they approach the ear, finally tapering down to nothing.

Mr. Mercer. Mr. MERCER: In many towns the poles are much too heavy, and the engineers in those towns evidently think so too, as I have noticed

that lighter poles are being used when new routes are constructed. Mr. Mercer. The standard poles are quite light enough, and, moreover, should be still further strengthened at the bottom section to stand up to the evils resulting from sweating. I have never yet planted a span pole with only 2″ rake except in rock, and in other cases never less than 4″ to 6″, according to the soil, the result being that the span wire is pulled up taut, and gives about 12″ sag with the weight of the trolley wire on it. With 24″ sag in a 40 ft. span, and such light poles as the authors recommend, I think there would be considerable whipping after a car had passed at speed. I would not dispense with bases, but think that they should be shorter and lighter than those generally used, and certainly should be ventilated. The authors state that several feet of water have been found in poles, and that it is due to sweating. I think this impossible, and that the accumulation is due to absence of a finial, or to water from the concrete after planting. All guard wires should be thoroughly connected to the rails every 200 yards. The idea of inserting a shield between the trolley wire and the hanger seems excellent, and it has the recommendation that it can be replaced easily with a new one when required. It has been stated that "figure 8" wire gives an increased contact area to the trolley wheel. Could one depend on the wire keeping its vertical position either on straight line or curve work? I understand that in Coventry, when circular wire is in use, mechanical grooved ears are now being employed, a groove being pressed into the wire by a clamp and die. This seems satisfactory, and tests show that the pressed wire is every bit as strong as the remainder.

Mr. R. N. Tweedy (*in reply*): I should like to pay a tribute to the Mr. Tweedy. important share which Mr. Dudgeon has taken in the preparation of the paper. It is he who has discovered that the deterioration of hanger bolts and secondary insulators is due to electrolysis, and it is he who has followed through to logical conclusions the whole subject of the wear of trolley wire and ears.

With regard to Mr. Sayers' important communication, I have to admit that gentleman's superior knowledge of such a difficult subject as electrolysis, but I have samples on the table which go far to prove my assertions, and a careful study of all the circumstances which attend the deterioration of insulators, of which the paper itself is an inadequate expression, leaves little room for doubt in the minds of the authors that not only are bronze bolts not exempt from this insidious form of decay, but that they are actually more prone to failure than iron bolts.

Undoubtedly the exact history of failure of these insulators will form a deeply interesting subject for research; meanwhile the best thing to do is to prevent the progress of deterioration by keeping the primary insulators dry. Mr. Dudgeon and I are indebted to Mr. Sayers for his complimentary remarks about our shield, and can assure him that no dust or spiders' webs could accumulate between the shield and hanger so long as the linesmen did the smallest part of their duty.

Mr. Tweedy. There is some doubt in my mind as to whether Mr. Sayers objects to slack trolley wire or to slack span wire. Personally I think that trolley wire ought to be as tight as is consistent with its ultimate strength, and that span wire ought to be much slacker than it now is, although there is no necessity to go to the extremes of which Mr. Hill spoke.

Mr. Hill says that the size of poles must be determined by certain considerations, among which are the weight of the trolley wire and the tautness of the span wire. Our case for lighter poles is that first and foremost the sizes of existing poles and the sizes of the British Standard poles have been forced on us by the importation and general acceptance of a false standard of rake, while in the next place the size of the trolley wire has increased beyond the real necessities of the situation.

As to the satisfactory results obtained with gun-metal fittings attached to the line by galvanised span wire, it is only to straight line hangers that we referred, and it is difficult to see how the best galvanising can prevent local action between the dissimilar metals. Apart from that question altogether, the use of gun metal is an extravagance so long as malleable iron or some such cheap metal will give satisfactory service.

If really satisfactory ears can be made for grooved wire we have not seen them, and a sample on the table, which has been got from a newly constructed line, is no better than a deep grooved ear, as the sides foul a trolley wheel. With regard to trolley wire, we declare that given proper ears which do not obstruct the passage of trolley wheels by coming into contact with them under any circumstances, and given a wire no larger than 2/0 S.W.G., but rolled with a specially large radius for the under side, then the heaviest city service will not depreciate that wire to anything like the extent that the largest wires now used are depreciated under the generally defective methods of suspension now in use. While the strength of an uncircular section is perhaps 10 per cent. or 15 per cent. less than the strength of an equivalent circular section, we contend that 1/0 S.W.G. circular wire has proved itself strong enough for safety over ten years' service under bad conditions, and that no harm will follow the use of 2/0 S.W.G. wire, even though its ultimate strength is no greater than 1/0 S.W.G.

Undoubtedly the degree of tension on the trolley pole is of great importance wherever anything but figure 8 wire is used, but our point was that the wear of the wire *between* the ears seems to be unaffected by the tension; that is to say, the measurements given go to prove that other point, that rolling friction is of little importance as a factor in wear. Viewed in this light, Mr. Hill's criticism of the observations made under a low bridge are nullified.

It is particularly interesting to observe the difference between Mr. Hill's and Mr. Brown's opinion of the British Standard pole.

Mr. Yerbury lifts his bases every year. Would that every one did the same! Even then they were better scrapped.

Mr. Yerbury expressed surprise that the new phosphor bronze

trolley wires are not used more, but the extra strength they give is not required, while the resistance is very much higher than that of hard drawn copper. Mr. Tweedy.

Until to-day I had not heard of "sheradised" hanger bolts, but there is a sample on the table now, and I assure you that no matter how the metal is treated, so long as it remains metal, and so long as the "protective" coating is metallic, electrolysis will set in with finally destructive results so long as leakage occurs, and leakage cannot be prevented unless the insulator is kept dry. Galvanising and sheradising tend to increase the life of the bolt, but cannot do away with the trouble.

Mr. Pringle's appreciatory remarks are gratifying, and I can assure him that considerable attention is now being given to the problem of attaching the patent "shields" to the hangers without removing the bolts.

It is necessary to clear up the general misconception of our meaning when we spoke of the serious wear due to arcing. We do not refer so much to the arc struck sometimes between the trolley wheel and the end of an ear at the moment of impact, or at the moment of leaving, as to the arcing which is not visible to an observer who is not on a level with the wire, due to the excessive current density at the actual contacts either when the car is taking heavy currents from a small section wire, or when the section of the path presented to the trolley wheel is enlarged and the contact accordingly diminished when an ear of the ordinary type is encountered.

Communicated : Mr. Browne shows clearly that the weight of the pole need be no true indication of its strength, which must depend on the designer. If taper poles could be made so that the thickness of the plate decreased with the height, sectional poles would not be used, and ideal conditions of maximum strength for minimum weight would obtain. A taper pole is more graceful than a sectional pole, and would be used generally if its weight and price were not comparatively higher.

More than one contributor to the discussion said that 2″ rake on a pole standing 25 ft. above the ground is not discernible by the eye. That rather points to a rough-and-ready method of raking, which gives added force to our suggestion that poles are abused. A raking level costs but a few shillings, and can be used by a labourer. It will indicate the smallest rake, and will do more to bring constructional engineers to our way of thinking than an infinity of papers.

The flexibility of the South Staffordshire poles must tend to decrease the hammering and sparking which Mr. Prosser has noticed, and these evils are due solely to the particularly bad type of ear which is used on those lines.

We would prefer something less expensive than a 5-ft. base weighing 500 lbs. and over to protect poles on the "wind and weather" line.

Mr. Prosser's remarks on the subject of ears show that he has not grasped its elements. The best reply to his scepticism about the new

Mr. Tweedy. form of ear exhibited is that such an ear has been in service for several months with entire success, and that further trials are to be made. He has not mastered the simple construction of the ear, for he speaks of the figure 8 portion being soldered to the "clip," whereas it is soldered to nothing but the wire.

Mr. Hartley's objection to malleable iron fittings carries little conviction to our minds, for we know it to be possible to buy fittings which are properly galvanised, and fitted to stand the atmosphere of the Black Country.

As a general thing, whether poles or fittings are in question, rust is allowed to appear before painting is done, and the surfaces to be painted are not properly cleaned. The result is certain to be unsatisfactory.

Mr. Hartley's testimony with regard to the generally satisfactory condition of poles having no heavy bases is gratifying. His reasons for preferring the mechanical ear for circular wire, and his opinion that the new "figure 8 ear" will not suspend the wire efficiently, are refuted out of his own mouth, for he owns that the wear of trolley wire at the mechanical ears is "much greater" than elsewhere, and he admits that his experience with figure 8 wire has been satisfactory.

What the "figure 8 ear" does beyond question is to endow circular wire with all the advantages of figure 8 wire, while the efficiency of its suspension has been proved in practice.

Mr. Fourniss, who has had much constructional experience, corroborates many of our views, but differs somewhat when he touches trolley wire. We are glad of it, for his measurements only show how much more work has to be done in this direction before anything like a dogma can be propounded. In the face of our more consistent observations of greater wear on a wire delivering heavy currents than on another delivering small currents, the finding that out of 48 measurements the reverse was the case is somewhat astonishing, and we should like to make careful inquiry as to the conditions. Similarly we can do nothing at present but accept with much reserve the interesting statements that trolley wire wears between points of suspension like an immensely elongated cone, the base being always at the positive end of the direction of motion, and that it wears more at the leading end than at the trailing end of an ear. The latter phenomenon is quite opposed to the general theory.

The corrugations of which Mr. Fourniss writes are commonly seen on the trailing end of an ear and the adjacent wire, and may be the result of a too rigid suspension. Without much doubt they are caused by vibrations of the trolley pole and of the wire itself.

Perhaps Mr. Fourniss has not had long enough experience on a running line to realise the trouble which can be given by the failure of hanger bolts. After three years most bolts have depreciated heavily, and renewals are frequent.

The recommendation to fix reel insulators horizontally, instead of vertically, as usual, is based on experience, but refers more to flexible

suspensions than to spans. The reel in that position is able to withstand the shock of a de-wired pole hitting the suspension wire much better than if it were vertical and the strain had to be taken by the flanges. Mr. Tweedy.

Mr. Mercer fights our battle in all he says about poles, for we contend that the rake and the sag to which constructional engineers in England have become accustomed are too large and too small respectively, and he merely informs us that he is one of them.

In answering his question about figure 8 wire keeping upright, we can only refer him to the fairly numerous places in which it is in use. We understand that the trouble he apprehends is not encountered in any serious degree. There can be no doubt that the "flattened circular" wire which we recommend will have no tendency to turn, and it is well to repeat here that all circular wire, but especially o S.W.G. wears quickly to a flattened running surface in order to provide the necessary area in contact with the trolley for the current delivered at any point. Naturally, this applies only to wires which deliver fairly heavy currents.

The expedient of grooving the trolley wire at Coventry for the reception of mechanical ears is brilliant, but we must point out again that grooved wire ears always foul the trolley wheels when the latter are part worn.

Discussion in London, May 17, 1906.

Mr. H. M. Sayers: I have already had the pleasure of contributing to the discussion on this paper at Birmingham in writing. As I have not a copy of my remarks with me it is just possible I may repeat myself or refute the statements I then made, but I must take that risk. The most valuable portion of the paper is the gathering together of experience as to the nature and probable causes of the wear in different parts of the overhead equipment; and the natural deductions which we may be able to make by considering these facts as to modifications in materials and methods of construction which may make the repairs and depreciation bills less important in amount than at present. Mr. Tweedy kindly remarks that he agrees with a good deal of what I said rather more than a year ago before the Tramway and Light Railway Association. In that paper I mainly dealt with materials and the general methods of construction. The most novel fact brought out by the authors is the wear of trolley wires at and near the ears. His suggestions as to the cause of that wear excite my criticism. I have no doubt that sparking plays a considerable part. The difference between the wear on an uphill wire and a downhill wire certainly goes to prove that. But what causes sparking? Insufficient area of contact is suggested. I take leave to doubt that. As long as there is contact between the trolley wheel, pressed upward usually with a force of about 20 lbs., and the bright surface of the trolley wire, I do not think there will be perceptible sparking with any current likely to be taken by a tram-car. We all know that a very large current density can be Mr. Sayers.

Mr. Sayers. borne for a short time across clean metal surfaces under considerable pressure, and I think most people will agree with me that if even 60 or 80 amperes passes across clean contact surfaces of not more than two or three-hundredths of a square inch there will not be any appreciable sparking. If the current goes up to 200 or 300 amperes, as it may occasionally on an up grade and a slippery rail, there may be sparking. That sparking does take place is quite certain; you have only to watch the majority of lines on a not very dark night to see it. I suggest that sparking is caused by breach of contact between the trolley wheel and the wire. The trolley wheel dances; the arc results. Of course there is the direct mechanical effect. If the wheel dances it gives the wire a blow on its upward movement; the two events do not occur exactly at the same point. I think these two things which do not coincide in position account for some of the peculiar type of wear which the authors have put before us. I therefore say that the cause of the wear at the ears is not the use of the round wire or insufficient contact as contact, but it is due to dancing of the trolley wheel brought about by mechanical causes. To some extent it may be due to running with worn wheels. There is a tendency to keep a trolley wheel on its head longer than is desirable for the good of the overhead equipment. A trolley wheel does not cost a great deal, and it is worth its weight of metal even when it is scrapped. It is better to scrap a trolley wheel at the end of three or four thousand miles than to keep it on for another two thousand and make dents in the trolley wire. Then the tension on the trolley boom has something to do with it, and so has the length of the trolley arm. The method of suspension is really the essential point. It has been remarked by the authors that rigid or elastic suspension seems to make comparatively little difference, that with a rigid suspension one may get no wear at all, and with fairly elastic suspension one may get heavy wear. I suggest it is not a question between rigid and elastic suspension, it is a question of uniform rigidity or uniform elasticity of suspension. It is interesting to remember that on the Buffalo and Lockport Electric Railway, where cars were running at from 50 to 60 miles an hour several years ago, the trolley wire was carried by a superior galvanised iron wire. The trolley wire was hung to the iron wire at points, I think, about 15 ft. apart. That is a catenary suspension with a practically level trolley wire, not more flexible at one point than another. I suggest that differences of rigidity or of flexibility at different points of the trolley wire sets up a wave motion in the trolley boom which accounts for the jumping at the ears, and that that is the main cause of mechanical and sparking wear of the wire. Of course a badly made ear may catch the flanges of the wheel, and that accounts for trouble, but I take it no engineer of intelligence would put up such ears whether they were mechanical or soldered. My faith in the soldered ear remains very strong, but I have never seen a trolley line work better than the one on the Great North Road, where flexible ears and grooved wire are used. On that line you cannot hear the trolley wheel pass over the ear, nor can you see any spark. That is an exceedingly good piece of work. It

has been in use for about nine months now, and is in very good order. Mr. Sayers.
I should like to deal with one more point that Mr. Tweedy has raised in detail, the question of insulated bolts. Insulated bolts are the weakest point in the whole of our overhead work, and more modern ones are no better than the older ones; in fact, I noticed one of Mr. Tweedy's samples, a Dickenson insulator, which has lasted a great many years, but on 300 not 500 volts. It has a much longer creepage passage across the insulating material than the modern pattern, and I think that may partly account for its longer life. There can be no doubt that the principal agent in the destruction of these insulated bolts is electrolysis. The iron or the brass, as the case may be, is positive to the hood, and whatever current leaks across it results in oxidation of the metal. If iron, the salts formed are mainly oxide and carbonate of iron, unless there is a considerable amount of sulphurous acid in the atmosphere, when the salts will include a mixture of sulphates and sulphites of iron. Generally the iron salts are insoluble and bulky compared with the iron. That accounts for the splitting up of the insulating material. With brass the products of electrolysis are mainly soluble salts, and do not split up the insulating material in the same way. I am unable to follow the suggestion made in the paper that one of the products of electrolysis of brass would be a metallic skin over the insulating material. I do not quite see how that can occur. If any metallic deposit takes place under the conditions of voltage and current density that obtain, it would be arborescent, and would not form anything like a conducting film. However, there is the fact that under certain circumstances brass bolts are worse than iron. Something may be due to the particular atmospheric impurities of the district, and something to the alloy. I have tried to get brass, or rather gun-metal, bolts that were satisfactory for a long time, and have not succeeded. The makers seem reluctant to use the right material, or they find manufacturing difficulties which they do not care to explain. They will give you gun-metal bolts, but they are not satisfactory or strong. I believe that the cure for the whole thing is to do away with the present form of hanger altogether. Clip the trolley wire to the suspension wire, insulate the suspension wire at a sufficient distance from the trolley wire to escape the blows from dewired trolleys, then there is no difficulty in using porcelain insulators, which the experience of half a century or more has proved to be by far the most permanent and economical form of insulation ever used in any climate.

Mr. T. H. Schoepf: I think the authors recommend too strong measures in reducing the cost of overhead construction. Mr. Schoepf.

In many tramway systems I think the construction installed is too strong and excessive safety factors adopted. While I am an advocate of lighter overhead construction I wish to sound a note of caution to less experienced engineers, that they may not go to the other extreme in their desire to reduce the cost.

In rising to speak to-night my wish is to touch on a few points which experience makes me think may be of interest.

Mr. Schoepf.

The authors have called attention to the rake allowed for in planting poles, and have criticised strongly the American practice. Most of my experience has been in America, and I may be able to give some information which has not occurred to the authors. I have in mind a particular tramway located in a city where the temperature varies from 10° F. below zero to 115° F. This condition influences the decision of rake to be given the poles, and makes it necessary to provide a turnbuckle or other means of adjusting the span wires. Any engineer can figure this for the scheme he has in hand.

The authors have said that in America "any old" tree which happens to be at hand is trimmed of its limbs and used as poles. This is quite tiue as regards a few isolated tramways in sparsely settled districts where a tramway was required, but the possible returns were not sufficient to justify anything but the very cheapest construction. However, if you will compare the practice in tramway construction in the large and small cities of England and America you will be surprised how closely they agree.

I quite agree with the authors that bases for the poles are not necessary; they afford little protection, and do not improve the appearance. If you wish to use bases, select and install them with judgment, as they may prove a source of weakness. In America centre-pole construction has been used extensively, and bases were found necessary to protect the poles from mechanical damage, which practice has been carried to side-pole and span-wire construction.

The conditions to be met with in America are diverse, and I will mention the difficulties met with in planting poles at New Orleans; the conditions here are similar to Belfast, in that the sea level is close to the surface of the streets. Because of their cheapness wooden poles sawed to shape are used almost exclusively, and considerable difficulty was experienced in planting them. A template was made a trifle larger than the base of the pole; this was surrounded by concrete, and, after the latter had set, the template was withdrawn and the pole set in the opening. The space between concrete and pole was then filled with sand and a shield placed over this to shut out the water.

In some of the northern cities where considerable frost is experienced, it is almost impossible to keep the poles from shifting when the frost comes out of the ground in the spring. In one instance I have seen a pole surrounded by 12 ins. of concrete and set six feet in the ground pulled over at such a time.

I quite agree with the authors as regards the collars, and, to put it plainly, think they are rotten, but some protection should be provided at the joint.

Mr. Tweedy has qualified the authors' statement that figure 8 wire was used extensively in America. I have never been in Minneapolis or Milwaukee, but have been in most of the principal eastern cities and have never seen any of this wire used, and only in one place a grooved wire. My opinion is that a grooved wire so modified as to place the bulk of the metal in the lower globe, thus placing the centre of gravity low, will overcome the tendency of the

wire to turn as the trolley wheel passes. This, with a correct hanger, will certainly overcome much of the present trouble. Mr. Schoepf.

My own experience bears out the statement of the previous speaker that the wear is due to the dancing of the trolley wheel, and is primarily caused by sparking.

Mr. Tweedy has made a plea for a smaller trolley wire, and I think, in working out any particular scheme that one may have in hand, that the construction should be made such that the cost will be as little as possible in accordance with good engineering practice. However, where money can be spared there is no better investment than copper. I am not sure that one should go to such small wire as Mr. Tweedy suggests. The theory is probably correct, but the traffic considerably increases in ten years, and it is impracticable to renew the trolley wire because it has not served its full life of usefulness. For instance, I have in mind one place where we had a great deal of trouble on a line running out into the suburbs of Washington. This occurred at one particular part of the line, and we had to renew the wire very frequently. The trouble was due to a great many very severe curves on that portion of the line. As you probably know, in America the trolley wheel is not swivelled, it is rigid ; the harp of the wheel forms part of the trolley boom, and the wheel fits right in the harp ; thus there is no swivelling, which results in a great deal of wear at the curves.

Mr. Tweedy has spoken of the porcelain insulator, which is used almost exclusively in single-phase high-voltage line work. While it cannot be used in every case I certainly think it has very strong points recommending it for consideration in continuous-current tramway practice.

Mr. F. GILL : With regard to the question of guard wires, which is mentioned on page 169, so far as the telephone company is concerned, I see no reason why any tramway engineer who desires should not get notice if a bed of wires over a tramway is removed, and he could then take his guard wires down. I do not think we have the least objection to that. It also seems to me worth while for tramway authorities to consider whether it would not pay them to get rid of the crossings in some places by one transaction, by paying the cost of removal, rather than incur annual expenditure on guard wires. Mr. Gill.

I should very much like to hear the opinions of tramway engineers with regard to bonding poles to the track. We have had some cases, at least three, of cables being damaged owing to the tramway poles becoming alive. In one case a lead cable was put into an iron pipe, and shortly afterwards a contractor came along and put up a tramway pole touching the pipe ; owing to a breakage the pole became alive, the current passed from the pole to the pipe, along the iron pipe and cable about 30 ft. distance, and finally broke out in five places on to some lead water service pipes which crossed the pipe and track. That is one instance, and there have only been three instances of which I know, therefore I do not want to make too much of it ; but still there are some other considerations which will be obvious to everybody. One would like to hear what tramway engineers think as to the desirability

Mr. Gill. or otherwise of bonding to the track. With regard to accidents and secondary insulators, why should not they be put further out from the pole? I know of one case where a man working up the pole, depending implicitly on the primary insulation, touched the span wire between the two insulators, got a shock, and fell. A linesman should be able to take care of himself, but when painters, for instance, have to work up the poles, and they see an insulator, they think an insulator insulates. It seems to me you might avoid that difficulty, if there is no objection, by putting the secondary insulator further out. Then with regard to the porcelain insulators, telephone people have had a great deal of experience of porcelain insulators, and they find that corrugations are absolutely useless, even worse than useless. They get full of dirt, and the result is that there is a bad insulation. The experience is that the smoother the surface is on the outside the easier it will be washed by the rain, and the better will be the insulation.

On page 180, and in all the following tables, the original diameter of the wire is given as 0·324 in. maximum. I would like to ask the authors (because a good deal depends upon it, as it is the data from which they make certain calculations) whether they are certain it was that diameter, or is it merely a specification figure? I have found, in trying to arrive at the reduction of weight of copper wires, a good deal of difficulty on that very point. Wire varies as it comes from the manufacturer, certainly down to small figures anyway, and I would not like to say that because a wire was specified to be 0·324 in. it really was 0·324 in., and then to arrive at very fine calculations on that point.

I want to criticise very seriously one point made by the authors on the question of economy. It seems to me that they are really quite wrong on that point. Several items—light poles, for instance—are said to be more economical because the first cost is less, but the life is ignored. It seems to me to be quite a wrong method of dealing with the question of economy, if you do not take the annual expenditure for the life that you are dealing with into account. It may, for instance, be quite the proper thing to put up a heavier pole, if it will last you sufficiently long to justify that extra expenditure. In the same way with a span wire, it may be a proper thing to put up a much heavier span wire than the author, or anybody else, recommends, if in consequence of doing so it will last you a sufficiently longer time to justify the extra cost; and it is quite possible to arrive at what is the extra life which must be added in order to justify the increased first cost. I am not disagreeing with the authors' conclusions at all; this paper is not in my line, and I am not competent to say whether they are right or wrong, but we get too many comparisons of cost based on what I think is the entirely erroneous method of handling the matter—that is, on first cost.

Mr. Grogan. Mr. F. S. GROGAN: I should like to back up our American friend, and give you my experience in this country, which is quite in agreement with his in America, viz., that it is a very serious thing to recommend engineers generally to take such light poles for the construction of overhead tramways, with span poles especially. Mr. Tweedy has

told us that 18 ins. of sag on the light British standard pole will work out in ordinary practice quite all right. This comes almost as a shock to men who have been used to putting up tramways. You can call it a rule of thumb if you like, but there is a certain amount of theoretical reasoning in the heavy poles which we are using at the present day. I had a discussion the other day with an engineer on this very question, and we debated the point as to what strain should be put on the span poles. If you consider an ordinary span of average length, say 30 ft., the common practice is to put a rake on the poles of about 5 ins., and to pull that rake into the perpendicular, or nearly so, with the span wire, and when the trolley wire is erected we have a sag of somewhere about 10 ins. That puts a strain on each pole of about 820 lbs.,* and I think it is very wrong to put up the light British standard for this work. There is another question which enters into consideration. Mr. Tweedy's argument is that a less cost will be involved by putting a bigger sag in the span wires and reducing the strain on the poles. That may be so, but is altogether contrary to the general practice. It is introducing new ideas, and we do not quite know what is going to happen. You have a whole lot of "sloppy" overhead line, which is generally condemned, and this will lead to a great deal more movement in the wires, sideways and vertically, trolleys coming off, catching, etc.; therefore you will have an enormous force brought on to the poles at certain points, and probably snap them. In the present practice we get none of that at all, and it is a serious thing to recommend engineers to use such light poles. I would like to add also that, although it may work, no thought seems to be given to the future life of the poles. Another point is that we cannot always allow for the joints. On a three-section pole, which we use at the present day, although engineers specify a certain percentage to be tested, there must be many that get through and are erected which really would not stand the drop test. I, in my own experience, have had to send poles back to manufacturers, although passed by the engineer, on account of this fault. We should allow something for the joints of the poles, and also for the life of the poles. Mr. Grogan.

Mr. SAYERS: May I ask your indulgence, sir, to make a remark with regard to the last speaker's criticism of the light British standard pole? The British standard pole has no defined weight. What is defined in the British standard pole for each size is the outside diameter of each section, the minimum thickness, and the minimum tests; and the thickness of the tubes making up the pole can easily be increased by any engineer who requires special work. The light pole at specified tests suffices for straightaway work, but specially heavy work naturally involves the use of either larger poles or a stiffer pole made up of thicker tubes. Mr. Sayers.

Mr. GROGAN: In connection with what Mr. Sayers has just said, it seems to me that the general acceptance of the term British standard light pole is that we do not want to get more than 750 lbs. pull. Mr. Grogan.

* This figure is for two 4/0 S.W.G. wires, erected 9 ft. apart and the regulation 120 ft. between spans.

Mr. Sayers. Mr. SAYERS: That is the minimum. If you want a stiffer pole specify thicker tubes.

Mr. Grogan. Mr. GROGAN: When one speaks of the light pole one never anticipates that it is a special pole. It is a pole which stands 750 lbs. for a 6-in. temporary deflection.

Mr. Sayers. Mr. SAYERS: I should like to say, as a member of the Sub-committee of the Standards Committee which drew up the specification, that we thought that the weakest and smallest pole should be used.

Mr. Grogan. Mr. GROGAN: I would point out that when one speaks of the light pole, that light pole is specified for 750 lbs. pull for 6-in. temporary deflection. If you want a stiffer pole, it will take a greater number of lbs. to pull it for a 6-in. deflection, and therefore it is no longer a light pole of the British standard specification.

Mr. Sayers. Mr. SAYERS. It has the standard outside dimensions.

Mr. Pell. Mr. F. B. PELL: I should like to hear if any of the members have had any experience of cap and cone insulators in place of the ordinary bolt and straight line hanger casting. I suggest this insulator should be used instead of the porcelain one suggested by Mr. Tweedy. In the cap and cone hanger one has practically the whole mass made in an insulating material, the top surface of which acts practically as a watershed, and is kept clean by the rain constantly beating upon it. If any of the members could give us the benefit of their experience in the use of these insulators I should be glad to hear it; probably some members from America or from the Continent have had some experience.

Mr. Blackburn. Mr. G. R. BLACKBURN (*communicated*): I would like to congratulate the authors on having submitted such an excellent paper for discussion, especially in view of the fact that practically nothing has up to the present been written on the subject of overhead equipment of tramways.

Much has been made of the so-called dangers of overhead equipment, and the advantages which would be gained by its supersession by other systems, but as a plain matter of fact overhead equipment is absolutely as safe, given proper construction and upkeep, as any system which can be devised, and I am glad to see that the authors agree in this view.

The real danger, however, lies, as stated in the paper, in the fall of guard-wires, and it is undoubtedly time that every effort was made on the part of the three principal parties concerned, namely, the Tramway Authorities, National Telephone Company, and the Post Office, to do away with such crude devices. In my own experience infinitely more trouble has been caused by guard-wires than by any other portion of the overhead equipment.

On the subject of poles, whilst agreeing with the authors that on many systems the poles used are altogether too heavy, still I should not care to use the 500 lb. pole, which the authors consider heavy enough. For straight-line work 750 lbs. has been used throughout on the Bradford system, except, of course, on curves and other special places, which weight of pole has not been found any too heavy for ordinary

Mr. Blackburn.

use. The three sizes used are 750, 1,000, and 1,500-lb. poles. Of course the third size is only used at termini for anchoring, or for other exceptional cases, and the second size for curves. As pointed out, when guard-wires are entirely done away with, the height of the poles could with advantage be made much less.

I agree with the authors in their condemnation of bases and collars, which are not only absolutely unnecessary and serve no useful purpose, but do not even possess the saving merit of beauty. It is not feasible without incurring great expense to lift the bases for painting the poles underneath, as this lifting of the bases would necessarily mean the re-calking of each. If this is done then, to be strictly correct, all the fittings should be taken off also. Although it is quite common to bring the feed cables down the inside of the poles, still I venture to think that such a method is open to objection, as however well ventilated the poles are, a certain amount of sweating goes on, which in time breaks down the insulation of the cables. As an alternative to this method, I have in many instances brought cables in a wood trough outside the pole, and although cables brought down in such a manner will last very much longer, still I cannot deny that it does not add to the appearance of the pole, and that it looks rather unsightly.

I should be glad if the authors could suggest a better method than the existing ones, as it is undoubtedly a point of weakness on the overhead system.

I am in agreement with the authors when they state that the usual estimate of thirty to forty years for the life of poles is exaggerated, and this seems to be confirmed by the American practice, which at the present time consists in opening out round the pole and putting a sulphured sleeve on, in order to stiffen it at the point at which corrosion is going on very rapidly.

In nearly every case where poles were opened out great pitting and corrosion was found, and eventually a few years would have seen the pole giving way.

I regret I am unable to obtain the time these poles had been in use before this practice was considered necessary, but it is obvious that they could not have been in anything like the period which is usually stated as being their life.

With regard to the question of span wires, I have used in the past considerable quantities of 7/14s, but have lately changed over entirely to 7/12s, as I find that the life is so much longer as to compensate for the increased cost. This, of course, applies to a manufacturing town, and probably under better conditions, the 7/14s, as stated by the authors, would be heavy enough.

I agree with the authors in favouring binding in of guard-wires, as against the use of clamps, as experience shows that these are not anything like as satisfactory as well-bound joints.

I now come to the question on which I must really disagree *in toto* with the authors, namely, the question of malleable iron hangers.

After an experience of seven or eight years, I have no hesitation in

Mr. Blackburn.

stating that malleable iron is unsatisfactory for overhead use, and am sorry to see that the authors lay so much stress on the capital cost of bronze fittings.

The trouble, of course, with malleable iron fittings is that unless painted very frequently indeed they deteriorate rapidly, and eventually become a mass of rust. In fact, corrosion of malleable iron fittings is so marked that it cannot be kept down, except by the expenditure of a very heavy sum for inspection, which must be done more frequently than is required by the remainder of the equipment.

As a matter of fact, I have been steadily replacing out of revenue all malleable iron fittings on this system for the last two years, which comprises over 53 miles of route.

Several routes originally fitted five or six years ago with bronze fittings are to-day as good as the day they were put up.

I am aware, of course, that the cost of bronze is very much heavier than the cost of malleable iron, but when the price of scrap is taken into account, assuming now that both classes of fittings have to be scrapped, and taking current prices for brass, it is found that, for instance, a straight line hanger originally costing 2s., can be sold as scrap for 1s., and a double pull-off, originally costing 3s., can be scrapped for 1s. 5d., the scrap value of malleable iron being, as every one knows, practically nil. In fact, great difficulty is experienced in getting rid of it.

When to this is added the fact that, as far as can be seen, bronze fittings will outlast any other part of the overhead system, I think it will be considered that, many times over, it is actually cheaper to use bronze even if is more expensive in the first cost.

I have found practically no trace of local action on spans where bronze hangers are used—in fact, owing to the rusting of iron fittings, it seems feasible to assume, and it is certainly borne out in my experience, that spans carrying iron fittings will not last as long as those on which bronze hangers are used.

Although I would not definitely assert that no local action has occurred, still its effect is very small compared with the effect of the rusting which goes on irrespective of whatever class of fitting is used.

Now, as to the question of the failure of insulated bolts, which the authors have rightly ascribed either to bad materials or local influences. Whilst, of course, it is perfectly well known that insulated bolts will not last the life of the system, still I have personally examined dozens of bolts which, after being up five or six years, are still in very fair condition, and I think the conditions must be exceedingly bad to produce failure of bolts in the times mentioned in the paper. Of course the reason given for the failure of bolts is quite correct, viz., that oxidation begins at the exposed end of the bolt and gradually creeps up under the insulation until this is cracked, and forced off; but as a matter of fact this occurs, and I can show actual samples which have been taken down in places over which a trolley has never run, as well as in places on which a regular service is maintained. For instance, the effect of

oxidation is as marked in the case of bolts at the termini of lines as it is on a section with a constant service, and this therefore does not confirm the theory that by excluding water, which is supposed to be thrown up by the trolley wheels, from the interior of the hanger, oxidation will be arrested. Mr. Blackburn.

Also, according to one engineer who recently communicated his experience to the technical press, it appeared that the effect was just as marked on a line used only for feeding, and on which no trolleys ran, as on the ordinary service line.

I am afraid, therefore, that no good would be served by fitting each hanger with the shield proposed by the authors.

I find that oxidation can be arrested for a very considerable period if the bolts are thickly coated, before they have had time to oxidise, with Russian tallow, and this allowed to remain on the bolt after the same has been screwed into the ear.

This, of course, helps to keep moisture from the only exposed part of the bolt, and therefore the only part which can rust. As previously mentioned, with the best bolt obtainable a life of six or seven years is easily obtained.

There is, however, a good field for the design of a hanger of a different type, as proposed by the authors, but I do not think that porcelain would be the best material to use in conjunction with such a hanger. Part of this system consists of a leased line which is equipped with porcelain insulators, and a plain metal bolt in the manner proposed, and considerable trouble has been experienced owing to the breakage of the porcelains.

It should not, however, be difficult to make an insulator which would carry a plain metal bolt in the same manner, and of such material as would not crack with alternate heat or cold, or from other causes.

I quite agree with the authors that Brooklyns are not necessary, as it is well known that when once a span is erected it is not necessary to tighten it at any time, and such fittings are probably a survival of American methods.

Up to the present, however, I have not come across anything which has been entirely satisfactory enough to take their place, and I should be glad to know if the authors can inform me of the makers, or let me have samples of porcelain reels for this purpose, and which, they state, are now coming into use.

I have already tried porcelain for this purpose, but found that the same trouble was experienced as with the primary insulation, namely, that they were not mechanically strong enough to withstand weather conditions, and the somewhat great strain which comes on them in carrying any heavy span.

Globe insulators and links for use on flexible suspensions are, of course, very satisfactory, and will last a great many years, but if, as the authors state, small porcelain reels at the cost mentioned are now on the market, and are quite satisfactory, there is no doubt that a considerable saving can be made.

As the authors state, the section insulators must be bad indeed, when

Mr. Blackburn.

linesmen cannot work with safety when "protected" from the source of supply by 12 in series. Personally, I have never seen such an instance, and trust that I never may. I should, in fact, think a section insulator was bad if it was not possible to isolate a line and work on it from a tower waggon with only one in circuit, and, as a matter of fact, it is quite possible to obtain section insulators as good as stated.

With reference to secondary insulators, I am afraid I must disagree with the authors in again preferring bronze, although there is no doubt that a certain amount of electrolysis does go on. I consider the effect of rust far more marked than the effect of electrolysis, and far more necessary to take into account.

With regard to the authors' statement that no one can hope that the insulators, taken as a whole, can last fifteen years, I think no one can disagree, and if there were any method by which such insulators could be made to stand that period, I am quite sure that every tramways engineer would welcome it immediately.

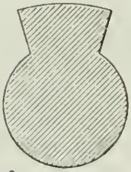


FIG. 1.

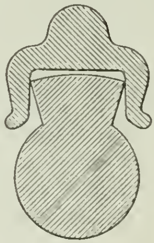


FIG. 2.

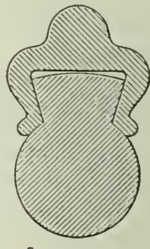


FIG. 3.

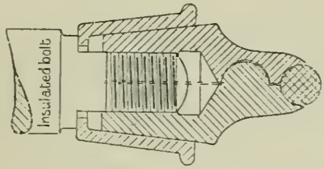
With reference to trolley-wire ears, I may state that I have tried nearly every make on the market, viz., sweating, mechanical, tapping, grooved, and various other types of patent ears which have come up from time to time, but after an extensive trial of all classes I find the most satisfactory from every point of view up to the present has been the deep-grooved tapping ear. These ears are simply tapped over the wire—not, however, completely covering it—and require no soldering.

Presuming that ordinary inspection is properly carried out, these ears give equally as smooth running as the sweated ear, without the danger of overheating which exists with that type. They are easily and quickly attached, and will last, even with the heaviest service, for several years. The wear, also, at the ends of the ears is at least as little with this type of ear as with any other type that I am aware of.

There is, however, a very ingenious ear now being introduced, called the "Swift-sure" ear, which grips the trolley wire in a couple of grooves which have been previously made in the wire by a hydraulic press. This method is, however, only applicable if the diameter of the wire is such as to allow it to be so gripped, as it will be obvious that the lug of the ear must not extend too low down, otherwise it will foul the trolley wheel. See Figs. 1, 2, 3.

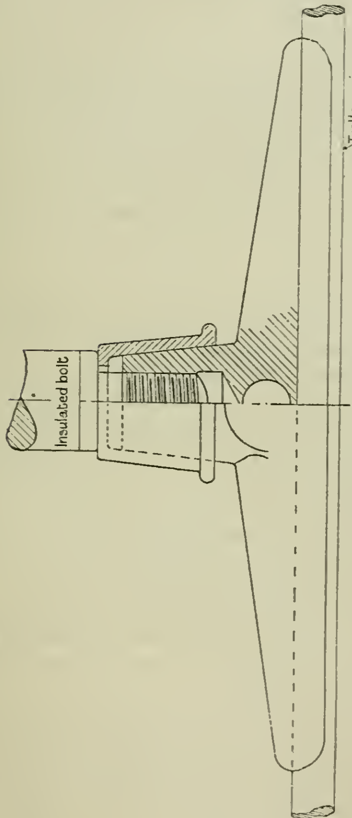
Mr. Blackburn.

The grooved section of trolley wire hardly seems to be meeting with the favour which was at one time expected of it, as there is no doubt great difficulty is experienced in getting the trolley wheels to clear the



SECTION

FIG. 5.



ELEVATION & SECTION

FIG. 4

ears, and this difficulty will, I am afraid, apply to the previous type of ear also.

Figure 8 wire I have had no experience with, but understand that it is very difficult to erect, and wears very unevenly.

I should be glad to know whether the authors have had any experi-

Mr. Blackburn.

ence with phono-electric circular wire, as I believe that this has given remarkable results when used with tapping or mechanical ears.

Personally, I think that circular wire, held by some form of mechanical ear from above, will still be very largely used for some time to come.

Another type of ear which I have experimented with here, and which has given very good results, is illustrated on p. 215 (see Figs. 4 and 5), and although at first sight it would appear that the wire would very quickly drop out, still, nearly twelve-months' experience has proved that such is not the case, and that there is very little, if any, danger in using these ears, presuming always that proper inspection of the overhead is carried out. These ears give very smooth running, and are exceedingly easy to put on.

I am sorry to see that the authors are recommending a type of ear which requires soldering, as any one who has had practical experience of the conditions of night-work, when work of this description has to be done, will realise the difficulties of properly soldering ears on. Personally, I should be very sorry to return to soldered ears, after having used mechanical and tapping ears for several years past. Such good results have been obtained from these types of ears that I should consider it a retrograde step to return to soldering, however good the ear itself was.

I am sorry that I also cannot agree with the authors on the question of size of trolley wire for use, as I consider that it pays to erect 0000 wire, although the original cost is rather heavy.

For mechanical reasons it is desirable to have a large diameter of wire, and all the early lines which were equipped with 00 wire on this system had, after a few years, to be replaced, owing entirely to mechanical weakness ; again, it should be borne in mind that although 0000 wire involves a heavy outlay, still there is a corresponding large return as scrap when the time arrives for the wire to be taken down.

I do not really think that many engineers would care to return to the small size given in the paper after having used 000 or 0000 for many years, and seen its excellent wearing qualities.

With respect to the authors' conclusions on page 180, I am in accord, and can confirm the fact that wear due to rolling friction is negligible. This is confirmed by the fact that on many sections here the up and down wires wear nearly equally.

Sliding friction is, I believe, with the present free-turning trolley heads almost negligible, but the most serious thing, and which causes most wear, is undoubtedly arcing and bumping, especially the latter, on the facing ends of ears which are slightly worn.

Attempts are now being made to reduce sparking by the use of copper trolley wheels and copper ears, both of which have a considerably increased conductivity over the ordinary brass wheels and ears.

Bumping, I believe, can be largely done away with by the use of some form of ear or trolley wire which will leave perfectly free under-running for the wheel, and also by having complementary trolley wheels. With regard to the authors' fourth conclusion, probably the presence of an

impure atmosphere, on further investigation, would be found to have some effect, but I regret that I have no data which will enable me to form any idea as to whether such would be the case. Mr. Blackburn.

I believe, also, that the method of suspension does not materially affect the wear, and that the effects of height of trolley wire and pressure of trolley wheel are *the* determining factors in the life of trolley wire.

It is of the utmost importance that an approximately uniform height should be maintained throughout the system, and I am sorry to say that this point has not received all the attention in the past that it deserves.

Pressure of trolley wheel against wire is, perhaps, the most important of all, and every pound this can be reduced will materially lengthen the life of the wire.

I should be glad to know what the authors consider a fair tension for an ordinary $4\frac{1}{2}$-in. wheel—17 ft. pole, (1) with straight under-running, and (2) with overhanging wire.

In conclusion, the authors are to be congratulated and thanked for having brought forward such an interesting paper, and for having given us results of investigations which have evidently extended over a very considerable period of time.

Mr. Tweedy (*in reply*) said: I am very sorry that the discussion has been so short; and it seems to me to be a pity that this opportunity of obtaining expressions of opinion on very practical points should have been lost in some degree. Mr. Sayers is not exactly right in saying that the novel fact on which we dwell especially is the wear of trolley wires at and near ears. While we say that to use the ears that are almost universally used on round and grooved wire is to court destruction of the wire always, and of the ears wherever current is taken, we hold that the use of non-fouling ears will overcome that trouble; but the wear which is perhaps more important than any is that which takes place on any wire from which current is drawn by trolley wheels, and naturally that is seen more distinctly than anywhere on the up line of hills, at starting places, and on the down line of hills where motormen have the pernicious habit of reversing the motors for braking purposes. We have proved this over and over again. Mr. Tweedy.

This wear is caused by some action of the current passed, and the only action which occurs to us is some form of arcing—invisible arcing, if there is such a paradoxical thing—which removes metal from both wire and wheel because the contact area existing between the wheel and wire is too small, and perhaps even more because the conductivity of the gun-metal wheel is comparatively low.

Mr. P. J. Pringle and the British Johns Manville Co. have thrown light on this point quite recently by their independent investigations with trolley wheels of pure copper, and it is possible that contact area has no more to do with the wear of current-giving wires than Mr. Sayers thinks, but that low conductivity is responsible for the greater part of it.

In the light of those experiments we are able to explain more satisfactorily than by Mr. Sayers's theory of dancing trolley wheels the

Mr. Tweedy. extraordinary wear to which a fouling ear (*i.e.*, the shallow or the deep-grooved ear, or the "all-round" ear, one of which is used invariably for round wire) is subjected when wheels collect current from it. However uneven the under surface of such ears may be when new, it is arced flat and smooth in a time which is longer or shorter according to the current taken from it, and that wear may continue until the wheel can travel on the bare trolley wire; that is to say, until the only part of the ear remaining is above the horizontal diameter of the wire. Unfortunately in many cases before this happens the trolley wire itself has been reduced in the process, and the general practice is to remove the ear which has caused all the trouble just when it has reached a nearly harmless stage, and to put on a new one of the same crude design, but long enough to cover over the patches on the wire at the ends of the old ear where the effect of bumping is added to that of arcing.

It is not uncommon to renew ears on the up line of a hill once, twice, or even more times a year, while the ears on the down line wear almost inappreciably, and might last ten or twenty years if the bumps which they make the wheels give the wire would let them. Meanwhile, the trolley wire which these current-giving ears are holding is wearing, but at nothing like the pace of the ears, because only the wheel is a poor conductor, whereas the ears may be of even higher resistance than the wheels. Use pure copper wheels instead of gun metal and the life of the wheels is known to be increased five or six times, but nothing is known yet as to the effect on the life of the ears.

Use copper "fouling" ears as well, and it is not unreasonable to suppose that both wheels and ears will live longer still. Use non-fouling ears such as the figure 8 ear or the loop ear, and wear at the ears is reduced very nearly or absolutely to the same amount as the wear on the free trolley wire, which almost certainly will be given a longer life if wheels of the highest conductivity are used.

For these reasons it follows that the life of the high tensile strength but low conductivity bronze wires, which have been tried on several British tramways within the last few years, ought not to be so long as that of the higher conductivity pure copper wire, to which we are more accustomed.

Bronze wire was introduced under the mistaken idea that hard drawn copper is not strong enough, and it is not likely to become popular.

It is important that the position which we have taken up should be quite clear, and that is our excuse for labouring the question of ears and wire still further.

Quite apart from the kind of ear used, the current-giving trolley wire throughout its length will wear at a quicker rate than the parallel wire from which no current, or not so much current, is taken. That holds always for 1/0, and in a less degree for 2/0 S.W.G. wires, but it is probable that the larger contact areas of the heavier sizes counterbalance the effect of low conductivity wheels, and that consequently

the difference in wear is absent or not so marked. Fouling ears will wear in the same manner whatever the size of wire. Mr. Tweedy.

It is impossible for us to view the wear at the ears in the same way as Mr. Sayers, who attributes it all to definite and visible arcing brought about chiefly by the dancing of trolley wheels and partly by worn wheels. None of the material evidence which we have been able to gather upholds that view.

We admit that dancing is a contributory cause, but hardly an important one. The visible effect of dancing may be seen often on ears from which current is not drawn, and under which the wheels travel at a fair speed. The underside of such ears is rolled into waves which are V shaped with the point heading in the direction of motion. Those waves are due to vibration caused by the wheels striking the end of the ear and dancing along it with varying pressure, but they are not seen on current-giving ears because arcing (as used in our special sense) has smoothed out the waves directly they began to form. There is some evidence to show that when trolley wire and ears are held quite rigidly, waves do not form under any circumstances.

Mr. Sayers says that no intelligent engineer would put up mechanical or soldered ears which foul trolley wheels. If the wire is of grooved or figure 8 section there is nothing to prevent smooth running, although there are many hundreds of grooved ears which do foul, notwithstanding that they have been put up within the last two years; but we should like Mr. Sayers to show us 1 per cent. of the existing tramways in Great Britain which use non-fouling ears with round wire. If he can do that we will concede the remaining 99 per cent.

There is no reason why non-fouling ears should not have been used from the beginning, as we have demonstrated in practice with our "figure 8" ear, but the fact remains that nobody has believed—and most people do not believe yet—that soldering to the semi-circumference of a 1/0 trolley wire is safe.

Bearing on this, we have Mr. R. F. Browne's permission to quote a test which he made to determine the *minimum* area of soldering required to hold up a trolley wire.

He soldered an ordinary deep-grooved ear to the semi-circumference only of a length of 1/0 S.W.G. wire, and after supporting the wire near the ends of the ear he attached a dead weight of 120 lbs. to the lug, and tapped the wire with a hammer, to imitate the action of a dancing trolley wheel.

The ear was cut away at each end 1″ at a time, and the same tests applied until the length was reduced to 3¼″, when the solder began to give way (Fig. 6).

From that experiment it is well seen what a huge and unnecessary factor of safety there is with 12″, 15″, or 18″ ears as commonly erected, and what little need there is for fear when we propose to reduce the soldered area by a small amount (figure 8 ear).

The wear on the wire, as a function of the tension of the pole, is somewhat open to question, and it seems very doubtful whether variations in tension cause any considerable difference in the wear. With

Mr. Tweedy. regard to the difference between the wear on the up and down line, these two 36″ specimens of splicing ears give a good idea of what happens.

The ear from the up line has worn absolutely flat on the bottom, and the two sides are worn like the sides of a trough. The ear from the down line, from which there was no current taken at all, is hardly worn, and the surface is quite bright. On both there is a comparatively long piece, which is absolutely rigid, on which there are no corrugations; but on short ears, where the tilting action is rather exaggerated, there is corrugation, and it is sometimes, but not always, carried out several inches on to the wire itself. If the catenary suspension, such as is seen on the Buffalo Railway and on high-tension single-phase railways generally, is good—and I believe it must be good for high speeds—then the objection which was raised by Mr. Grogan

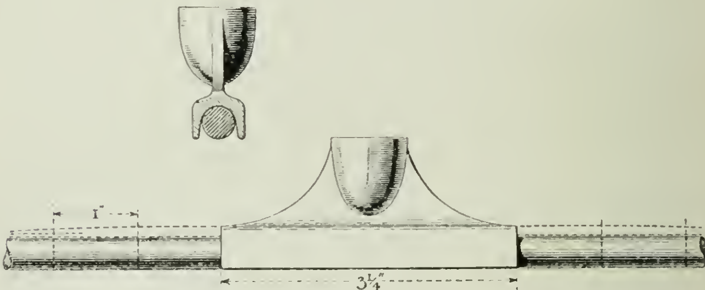


FIG. 6.

to sloppy spans has very little weight, for the catenary suspension is infinitely sloppy, but the horrors which that gentleman conjured up do not take place. I rather take exception to his objection to the introduction of new ideas. Although those ideas may be open to criticism, yet they are not objectionable simply because they are new. I am very much obliged to Mr. Sayers for his explanation of the chemical action which takes place with insulated bolts under pressure. With regard to the deposit on the brass bolts, I really cannot say whether it is metallic or what it is; but I do know that the reduction in resistance between the wire and the hanger is very marked indeed in a brass bolt that has been up for a year or two, and not only that, but the comparative insulation resistance of a brass and an iron bolt which have been up for the same time shows very badly indeed for the brass bolt. I have some samples on the table. In one case two iron bolts were taken and two brass bolts; they were held over saturated steam for one minute and allowed to stand for fifteen minutes; then the insulation resistance was taken with 500 volts, and the iron bolts had a resistance of about half a megohm, whereas the brass bolts had a resistance of, I think, 0·05 of a megohm, or something like that. They had been up the same time. It is very difficult to see with the naked

eye what the deposit is, and I have never had an opportunity of getting it analysed. Mr. Schoepf suggested that we had overlooked the different conditions which are common in America. We have not overlooked them; we quite admit that the conditions are very different, especially with regard to the range of temperature, but what we did say was that the Americans had come over with that experience in their minds and had acted on it in England, without considering first what the English conditions were: they transplanted American practice, but left the conditions behind. As for the plea for the heavy trolley wire, that it is a good investment even if it is too heavy, I do not know that that would exactly appeal to directors and committee-men at the present time, especially as tramway undertakings are not exactly gilt-edged concerns. I think probably the investment would be better employed earning dividends or in giving relief to rates. I stick to the point that the trolley wires that are being put up at the present time—such huge sizes as 3/0 and 4/0 S.W.G.—are very much more heavy than any consideration would require; that is to say, they are not required mechanically when smaller wires are suspended properly, and they are not required electrically, as Mr. Sayers has shown before. Traffic doubtless tends to grow in all live concerns, and we say in the paper that if traffic exists suitable for a five minutes' service, then perhaps the conditions warrant the use of heavier wire than 2/0; but who can say that the average, taken over the whole of Great Britain, is anything like three or five minutes? It is very much less than that, and therefore 2/0 wire is enough. Mr. Tweedy.

Mr. Gill asks whether all poles should be bonded to the rails. What happens now is that where there are no guard wires there is no pole-to-rail bonding, and where there are guard wires every fifth pole bearing them is bonded. It is seen, then, that bonding is considered solely in relation to live guard wires, not in relation to faulty insulators. That primary and secondary insulators do break down and communicate partial or full trolley wire pressure to poles, which are then a source of danger, will not be denied, and Mr. Gill has put forward instances of a different nature which had the same effect, so that there is good reason for the man in the armchair to say that every bracket-arm pole, every centre pole, and one pole of every span ought to be bonded to the rails. Actually we are of the opinion that no one would be warranted in going to such heavy expense unless the circumstances are quite exceptional. Animals have been killed by contact with live poles, but we have no recollection of any injury being done to a human being, and until good proof of certain danger can be advanced an order to bond every pole would be ruinously drastic. In such a case intermittent bonding would be useless.

In reply to Mr. Gill's question as to whether the 0·324″ is an actual figure, I cannot guarantee that at all, as it is so very difficult to find out what the actual new figure is in most cases, but so far as I can tell from measuring the wires that is pretty well within the truth. The variation is perhaps one-thousandth of an inch either way, but it may be taken as correct. I believe it to be perfectly true, as was suggested, that there

Mr. Tweedy. are two ways of looking at economy, and I merely say that from all points of view, not only on the question of first cost, but from the point of view of life, the lighter poles which are in use at the present time on the same lines on which the heavier poles are used for the same work have every chance of living as long, if they are properly cared for. If the collars and the bases are scrapped—at any rate, so long as they are lifted and the poles are painted beneath them—I do not see why the poles should not last as long as they are wanted. Then two speakers at the last meeting in Birmingham remarked that the trouble with poles which had not any bases on them was that they are attacked by dogs. That is perfectly correct, and the damage is serious. It is an interesting fact that the road side of a pole is not attacked at all; dogs prefer the pavement side. I have noticed that poles removed from a refuge in the middle of the road have been attacked on all sides. I say now, as I have said in reply to the discussion in another place, that if that is the only reason for putting on bases I do not think it is necessary to have them more than a foot high. Mr. Grogan criticised our remarks about the size of the poles. They are very open to criticism, but we did not attack the thing from a technical point of view in the least; we simply took the facts as they are. We say that here is a line with span-wire construction, with bracket arms, and with centre-pole construction and the same weight of pole with all the methods of construction. Obviously that is not necessary. If you have, say, a $7'' \times 6'' \times 5''$ pole weighing 800 to 1,000 lbs. for a span pole, obviously you do not want the same pole for a mile or two of centre brackets, and obviously also you do not want it for side brackets where the brackets are not of exceptional length. Again, there are instances of lines in which poles weighing 1,500 lbs. or 1,200 lbs. are used for span work, and in the contiguous town the span poles are not more than 850 lbs. or 950 lbs., both standing up equally well, and both, I submit, going to last equally long if they are treated properly. Both cannot be right, and the only question is which is right. The answer seems to be that it is the one which is lighter and is doing the work equally well. It is possible that even lighter poles could do the work. I do not at all think that sloppy spans are necessary to reduce the size of poles and strain on the poles. An $18''$ sag in a $30'$ road is not sloppy; it is quite æsthetic, and it soon would become just as unnoticed as the absence of bases. Even a $24''$ sag is nothing very remarkable. A gentleman remarked to me the other day that he had just left a town in which there were electric tramways, when it suddenly occurred to him that there were not any bases or collars on the poles; he had not noticed it when he was in the streets, so that the absence of those "ornaments" did not create any great repugnance at the time. In reply to Mr. Pell, the only objection to the cap and cone hanger is that it fails very much quicker than any other. I understand that it was tried extensively in America, and that it has been replaced practically everywhere by the type of hanger with which we are familiar. I believe the leakage was very considerable, although on the face of it that ought not to be so.

A few more of such communications as Mr. Blackburn has sent in

would have made this paper really valuable. Two features of that communication impress us particularly, the first being the pleasant confirmation of so many of our views, and the second that where his opinions and ours diverge the reason is either that we are not talking of exactly the same thing or that some actual experience about which there can be no dispute has been diametrically opposite in the two cases. Mr. Tweedy.

Perhaps if Mr. Blackburn once tried a 500-lb. pole for much of the lighter work he would find it as satisfactory as the 750-lb. pole, which is large enough for Bradford, but several hundred pounds too light for all the new tramways and most of the old ones.

It is interesting to hear of the rapid deterioration of steel poles in America, but it is possible that they have not been protected sufficiently at the ground line either by a sleeve or by frequent painting, or by bringing the concrete a few inches above the surface.

Evidently Mr. Blackburn has had considerable trouble with malleable iron fittings. Were they thoroughly well galvanised to begin with? If so, they ought not to have required painting for several years; then, had they been painted with good stuff before rust appeared, and had this treatment been continued at regular intervals, we think that malleable iron would be in favour at Bradford still, for our own experience is that malleable iron is eminently satisfactory in manufacturing districts which must be similar to Bradford. After all, one does not have to use gun metal for poles, bases, collars, bracket arms, and flexible-suspension brackets because we cannot keep the steel or the cast iron rust free; why, then, should it be necessary for hangers?

In the matter of local action, we can assure Mr. Blackburn that we have met with nothing but the exact opposite of his experience, and we even hesitated to exhibit specimens of decayed span wire because we felt that every one would take the action for granted. What prevents it at Bradford Mr. Blackburn must tell us, for we cannot suggest a reason. In the district bordering on Birmingham 7/12 and 7/11 span wire supporting bronze hangers requires renewal at the end of four to five years, because several strands are completely eaten away by that time, and the remainder weakened by local action between the steel and bronze, but 7/15 wire with malleable iron hangers attached has not been renewed yet, and looks good for many years longer.

On the point of failure of insulated bolts by what Mr. Blackburn calls oxidation, but we prefer to attribute to electrolysis, there is little more to be said at this moment than that trolley wheels obviously must throw rain-water into hangers unless special precautions are taken, and that equally obviously leakage is facilitated by this moisture. It may be impossible to exclude from the present form of hanger all moisture and to prevent the consequent action of leakage, but to check the chief cause of leakage and deterioration is not only possible, but has been accomplished by the use of the shield. All our observations go to prove that where hangers are not subjected to the throw of trolley wheels—as, for instance, at termini—

Mr. Tweedy. the acute deterioration noticed elsewhere does not occur, although there are cases, such as St. Helens, where the atmosphere is so heavily loaded with chemicals that insulated bolts fail long before the electrolysis following on leakage due to trolley wheel throw could have had so serious an effect, and in such abnormal cases it is quite probable that the shield will be of no avail.

The porcelain reels respecting which information is asked are capable of standing stresses of over one ton, so that the factor of safety under normal conditions is great, and no economical end would be served by designing insulators to withstand the extraordinary and unknown stresses to which one in a hundred may be subjected every five years by trolleys de-wired when the cars are travelling fast.

For reasons given elsewhere in this reply, we cannot agree with Mr. Blackburn that ears which surround the wire, or indeed any ear which is able to foul the trolley wheel, are the best. It seems to us that not a few engineers consider the relation between trolley wheels and ears only when the wheels are new. Under these circumstances ears which would be condemned if tried with well-worn wheels pass the test satisfactorily.

It is of the greatest importance that every one should realise as soon as possible that ears for round wire ought to have as long a life as ears for figure 8 wire, that that life ought to be at least equal to the life of the trolley wire under all conditions, and that, finally, the life of trolley wire when suspended by ears of the non-fouling type and served by swivel heads ought to be never less than ten years under the heaviest traffic, and anything over that figure for the average British service.

The only factor that might disturb this estimate is fatigue. Whether or not the vibrations set up in the wire by the mere rolling of the trolley wheels and the transmission through the trolley pole of vibrations from the car will be sufficient to crystallise the structure of the wire dangerously before the operation of other factors has brought about its superannuation, we do not presume to say, but we believe that when every one realises how much the life of trolley wire has been affected by fouling ears the general estimate of that life under the conditions attainable now will undergo a remarkable inflation. The same arguments apply to the question of the size and shape of wire to be used. Our investigations show that the diametrical wear on free 1/0 wire under a ten to fifteen minutes' average service is to be measured only in thousandths of an inch when non-current-giving, and in hundredths of an inch when current-giving, after four to six years' use. At that rate free wire might last for twenty years or more, but the 2/0 S.W.G. which we suggest as the *maximum* would wear much longer because of the greater available contact even when drawn circular, and the use of non-fouling ears will raise the whole length of wire to the standard of what we have called free wire, rendering quite unnecessary the use of heavier wires for life or for safety.

Grooved and figure 8 wires owe their origin to the desire to be rid of fouling ears, and in part to the craving for a non-fouling mechanical ear, although it is only quite recently that this ideal has been attained for grooved wire; therefore, when the same benefits can be got with circular wire it is simply a question for engineers whether grooved and figure 8 wire have any advantages remaining which justify their continued use on new work or for replacing circular wire on old work. Mr. Tweedy.

The bare statement that "it pays to erect 3/0 or 4/0 wire" ought not to carry any more weight than the erroneous but popular belief that surplus copper in cables is a good investment.

So long as fouling ears are used, so long must the tension of trolley poles be adjusted with care, and one of us used to set the tension for a Dickinson side-arm system between 17 lbs. and 20 lbs., but found that an under-running trolley did not give satisfactory results under 22 lbs. to 25 lbs. Before giving up the idea that a higher pressure than, say, 25 lbs. is injurious in itself, we ought to determine finally what effect pressures in excess have on current-giving and non-current-giving wires suspended by non-fouling ears. If, as we suspect, the effect is not injurious, the use of higher pressures may be found beneficial in other ways.

On Mr. Dudgeon's behalf, and also for myself, I beg to thank you very much for your kind attention, and I also desire to thank the Institution for allowing this paper to be brought up here for discussion.

The CHAIRMAN: I am quite sure that you will join very heartily in a vote of thanks to Mr. Tweedy and Mr. Dudgeon for their paper. The Chairman.

The resolution was carried with acclamation.

Proceedings of the Four Hundred and Forty-third Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 17, 1906, Mr. J. E. Kingsbury, Vice-President, in the chair.

The minutes of the Ordinary General Meeting held on May 10, 1906, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associates to that of Associate Members :—

William R. Barclay. | Harry B. Jenkins.

Messrs. H. Brazil and L. T. Healey were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Albert William Annetts.
Thomas Swainson Bell.
Edwin Harold Cunliffe.
Frederick Henry Edwards.
Ernest I. Farrow.
John Hammersley-Heenan.
Harvey Edward Mole.
Robert Rutherford.
Harold George Ade Stedman.
Thomas William Taylor.
Julius Edward Wedekind.
Octavius Noel Wightman.
George Wilkinson.

As Associates.

William Walker Hood. | Charles W. Mallins.

As Students.

Robert Fleming Benson.
William Bridger.
Arthur Brokenshaw.
John Gordon Patrick Cameron.
Harry Vine Chatterton.
G. E. O. De Smidt.
Walter Henry Edridge.
William Thomas A. Foot.
Charles Newdigate Garnier.
Thomas Reginald Graty.
Joseph Heynssens.
George Bertram Hopkins.
Edwyn Jervoise.
Alexander Rodger McCallum.
William Singer McMillan.
Gerald Hewitt Major.
Joseph Forbes Marsden.
Wilfred Harvey Miles.
Albert Ernest S. Minett.
Charles James Monk.
David Ormerod.
Arthur Charles Owen.
Robert Pennington-Sparrow.
Woodis Rogers.
George Cautlie Roos.
Jens Ernest Schmidt.
Herbert James Skinner.
Reginald Tomlinson.
Harry Topham.
William Hugh Young.

The Chairman: I am desired to express the regret of the President that he is unable to be here to-night, being unfortunately detained in the provinces by official business.

The evening was occupied in the discussion of Messrs. Tweedy and Dudgeon's paper, "Notes on Overhead Equipment of Tramways" (see p. 203.)

The meeting adjourned at 9.30 p.m.

MANCHESTER LOCAL SECTION.

ECONOMIC CONSIDERATIONS IN THE EMPLOYMENT OF STORAGE BATTERIES.

By J. R. Salter, Member.

(*Paper read March* 13, 1906.)

In the early days of what may be termed "heavy electrical engineering" there were practically two systems of supply to choose from, viz., single-phase high-tension system and the low-tension direct-current system.

It is perhaps hardly necessary to recall the heated controversy which arose in connection with the divergence of opinion on the merits of these respective systems, and which at the time divided electrical engineers into two factions. On the one side were the "low-tension men" and on the other the "alternating-current men." Sufficient is it to say that the great advantage claimed for the low-tension continuous-current system was that batteries of accumulators could be employed for the storage of energy which would allow of the generating station being shut down and the supply during hours of light load taken from the batteries. This advantage was considerable, as it represented in practical operation the saving of a shift.

What was considered a large power station at that time, however, is quite a small matter in the light of present experience, and it has been since established that the size of units installed in the early days in large towns proved utterly inadequate to meet ultimate requirements.

The conditions governing the electrical industry then were of an exceptional character, involving, amongst other things, capital costs for plant, which, regarded now from the point of view of the cost per kilowatt installed, appear unduly high by comparison.

Again, the load factors were small, the load fluctuated considerably, and the maximum load was a thing of wonder, and caused many an engineer in charge to "alternate" between awe and anxiety. One can all the more readily, therefore, appreciate the advantage which batteries represented in those days, where a shift could be saved without in any way militating against a continuous supply, whilst the maximum load could be more easily handled with the battery in parallel with the main generators. Under these conditions the battery established a reputation for itself which undoubtedly led to its more extensive use.

Since then, however, the development of electrical supply operations, the introduction of electric tramways, and the large development in the application of electricity to power purposes generally, have largely conduced to the exploitation of batteries for general use. Indeed, in the improvement and development of the use of the battery much skill and ingenuity have been expended, and of recent years the introduction of a reversible booster—to which Mr. J. S. Highfield has contributed so much—designed to automatically charge and discharge batteries, and to keep the potential constant at a given point, has resulted.

It seems to the author, however, that the record of utility established by the battery in earlier days, and the production of the reversible booster, have led engineers to overlook somewhat the economic considerations which should guide them in adopting any particular system of generation or supply.

In recent years, so rapid has been the development in electrical industries that the capacity and output of electricity works throughout the kingdom has been enormously increased. The load has become practically a twenty-four-hour load; there has been a considerable increase in the load factors, and consequently the relation between the maximum load at any one time and the average output has been altered. The considerations, therefore, which influenced the adoption of batteries in the early days have become to a very large extent modified, and the line of inquiry in this paper is in the direction of comparison between the advantages which the employment of batteries gives under these altered conditions and the cost at which those advantages are obtained.

Broadly speaking, four general advantages are claimed for the installation of batteries, viz. :—

1. Ability to shut down.
2. Improvement in load factor.
3. Saving in copper.
4. Constancy of pressure at the generating station.

Before dealing with the points enumerated it may be well to endeavour definitely to determine the function which the battery really fulfils. In the attempts which have been made to prove the advantages which are obtained from its use, it has been usual to compare the cost of the battery with that of steam-raising plant. Such a comparison is not, to the author's mind, a valid one, and is to be deprecated. The battery does not *generate* electricity, and is obviously incapable of maintaining a continuous output. It is nothing more than a transforming device, and the comparison of its cost should not be made with steam-raising plant, but with other transforming devices, such as static transformers, motor-generators, or rotary converters. It is indubitably inaccurate to compare the cost per kilowatt of a transforming device with the cost per kilowatt of generating plant. That this is so is apparent, since in arriving at the cost of the battery a time element is introduced, and this factor

is absent in dealing with the cost of the generating plant. It is generally stated that the cost per kilowatt of a battery is equivalent to the cost of steam and electrical plant, based upon the assumption that the battery is discharged at a three-hour rate. Why this particular rate of discharge should be chosen it is difficult to understand. It would be quite as reasonable for the advocates of batteries to assume a one-minute rate of discharge, and to show how infinitely cheaper the battery is in capital cost than steam and electrical plant; or, on the other hand, to assume a yearly rate of discharge, and to show how infinitely more expensive it is to install a battery than to install generating plant of corresponding capacity. The comparison, therefore, whatever rate of discharge is assumed for the battery, is obviously incorrect. It is, in short, a comparison between the cost of the capability of doing work and the cost of the rate of doing work, in other words, a comparison between the cost of "energy" and "power."

The author submits, therefore, that the battery cannot be regarded as a part of the generating plant, but only as a transforming device possessing certain storage ability, but it may be added that there are other electrical transforming devices having this advantage, although possibly not to so great an extent.

It may, however, be contended that the ability of the battery to store energy, which may be utilised when required, is at any rate a sufficient justification for regarding it as generating plant of a capacity equal to the difference between the maximum load which the plant is capable of supplying and the maximum output which the station is called upon to supply, but the author ventures to think that this claim cannot be substantiated. It depends essentially upon the rated capacity of the generating plant, and upon the relative capacity of the units for dealing with the changing loads during the various portions of the day. If it be conceded that the capacity of a generating plant is its capacity at its maximum efficiency, and that such plant can be designed with 100 per cent. overloading capacity for short periods (but, of course, with lower efficiency), then there is no doubt that any reasonable sized battery, such as one would install in any particular system, could not be regarded as possessing the modified advantage of being part of the generating plant. It is clear, therefore, that the capital cost of the battery cannot even be justified on the ground that it is an addition to the generating plant.

Having then endeavoured to define the functions of a storage battery, let us turn for a moment to a closer consideration of the claims which are put forward for its adoption.

It has already been conceded that there was a considerable advantage in the early days of electric lighting, but does this obtain at the present time, even with traction or power schemes of very moderate size? In modern practice there is, as is well known, little or no time in which to shut down a station supplying an electric tramway system: certainly there is not sufficient time to enable the station to be run with a shift less. The tramway load is generally required for twenty

hours in the day, and it is practically impossible to run such a station with two shifts. The third shift being essential, there is no reason why it should not be fully utilised ; and this remark applies whether the battery is installed in the power station or in the sub-station. It is claimed that the battery is a great source of security in the case of a breakdown in the generating plant, but is this really so ? As a matter of fact, to be of any great utility for such a purpose, the capacity of the battery would have to be enormous ; so great, indeed, that the author thinks there can be no question that the capital cost entailed for a battery to fulfil such conditions would not be justified ; and even if the capital cost were not so great, have we not arrived at a stage when generating plant can be considered reliable enough to justify the assumption that nothing short of a catastrophe would involve a breakdown of such a character as to altogether stop the supply ? I know of several large power stations operating tramway systems which have never been shut down through defects in the plant, and, with the exception of the Manchester and Bristol Stations, I can call to mind no case of a large power supply or tramway generating station which has ceased supply from such a cause. It will, of course, be appreciated that the author's remarks in connection with this section apply to traction and power schemes, and that he does not wish it to be thought that he considers that the battery does not still possess considerable advantage in the direction of auxiliary supply in small lighting stations. In such stations they have an output the greater part of which is supplied at such times as to enable the battery to take care of the load for the remaining part of the day, thus saving a shift.

Having dealt with the ability to shut down, the next and probably the most important advantage which is claimed for the battery is the improvement which it gives in the load factor. The question at once arises as to what the term "load factor" is intended to convey. So far as the author can see, the battery advocates take a particular generating set which is incapable of overloading ; they assume this set to be working in parallel with a battery which takes up the variations in the load, and they arrive at the load factor by taking the relation which the total units supplied bears to the units which that set is capable of producing if worked continuously at its full load, neglecting altogether that portion of the load which is taken up by the battery. If their claim to regard the battery as equivalent, or even partly equivalent, to a generating set is justifiable, either on the question of cost per kilowatt installed or in connection with its ability to assist in giving a portion of the supply, then, to be consistent, the capacity of the battery should be added to that of the engine set and the load factor worked out upon that basis. If this were done, there would be little or no improvement in the load factor by the installation of a storage battery ; but, as the author has pointed out, the battery can by no means be regarded as generating plant from any point of view, but simply as a transforming device.

It should be remembered, however, that some improvement in the load factor is due to the fact that with batteries the generating plant

in a given time has not only to supply the useful units in a supply, but has also to supply the units which are lost in the battery; and as the total annual steam consumption is made of two terms, the first dependent upon the number of hours the set is run, and the second dependent only upon the number of units generated, the cost of fuel per unit generated is bound to be less owing to the greater number of units generated, and which are lost in the battery; but it will be apparent that the cost per unit usefully supplied will not be so largely affected. That the loss in batteries is considerable, there will, the author thinks, be no dispute. In a case which recently came under his notice, a battery at the end of three years had only some 55 per cent. of its original capacity. If in tramway and power stations the capacity of the steam generators is assumed (as the author thinks it should be) at their rated capacity, and the overloading capacity is regarded as equivalent to the battery, then the load factor and the annual steam consumption should not exceed the load factor and steam consumption of the sets which the advocates of batteries assume for their purpose to be installed for a given set of conditions. In other words, the author claims that, with a properly designed station, the proper method of arriving at the load factor is to take it upon the rated capacity of the set and not upon the maximum load for any given moment.

Let us, however, assume that the load factor is improved by the utilisation of storage batteries, and then let us see to what extent the costs of generation are affected. The curve shows the percentage reduction in the costs of generation at various load factors. From this it will be seen that an improvement in the load factor of 33 per cent.—that is, from a 10 to a 13·3 per cent. load factor—only reduces the cost by 8 per cent.; to what extent it is claimed that the battery does actually improve the load factor the author has been unable to ascertain, but Mr. J. F. C. Snell * claims by the adoption of storage batteries to have increased his load factor from 45 to 53 per cent. With this improvement, the reduction in the costs is only 3 per cent., and the author suggests that this 3 per cent. improvement in the works costs is largely obtained by the extra units generated and which are lost in the battery. The question is, of course, different, as the author has already indicated, if a whole shift is saved, but with tramway and power stations, even on a small scale, this is not practicable, and it should be further noted that the load is so quickly variable from the maximum to the minimum, that the boilers are more or less unaffected, and are worked at a steady and economical rate.

The third advantage which is generally claimed for the installation of batteries is the saving in feeders, and it is suggested that to obtain this advantage the battery should be placed in sub-stations at distant points. In this way the current supplied to a distant point from the generating station instead of fluctuating would be more or less constant, as the batteries would deal with the fluctuations at the remoter parts of

* *Poceedings of Institution of Civil Engineers*, vol. 169, p. 143.

the systems in the same way as they are intended to deal with the fluctuations in the generating station. It is claimed, therefore, that it would be possible to utilise feeders of smaller sectional area, capable only of carrying the average current supply instead of the maximum. In the first place, it should be observed that the installation of batteries at sub-stations or feeding points to effect a saving in the cost of feeders does not affect the load factor at the power station, as in a scheme of moderate size the fluctuations or the maximum requirements at the various points do not occur simultaneously; and consequently, although the fluctuations in different parts of a large system may be very considerable looked at individually, they as a matter of fact may and usually do result in a good load factor at the generating station, as the maxima do not occur simultaneously. It should further be borne in mind that the only saving, so far as the feeders are concerned, by the installation of batteries in sub-stations, is the saving in copper. The same expense for insulation, covering, for laying and for opening and making good of roadways is involved whether the batteries are installed at the sub-station or not. That a saving in copper alone, by the installation of batteries at sub-stations of a sufficient capacity to enable feeders of smaller section to be employed, which is not more than balanced by the cost of the batteries themselves it is difficult to imagine. Such an arrangement further involves a continual cost by reason of the greater average loss in the feeders and by reason of the loss in the batteries. It would hardly seem, therefore, that this advantage is really worth serious consideration, and the author thinks it has been thrown out as an excuse only for the installation of batteries in systems which clearly do not justify their adoption in the generating station from the other points of view.

The other main advantage claimed for the battery is the constancy of pressure at the generating station, or the feeding-point; but the author contends that there is no special advantage in constancy of pressure at any one part of the system, if the pressure is fluctuating over the other parts of the system. All that is obtained is a geographical base from which the pressure differs on the other parts of the system; with a tramway supply, it is surely better that the pressure should rise with the load, and so enable the speed to be maintained.

After, therefore, analysing in a general way the advantages which are claimed for the utilisation of batteries, it would appear that the only real advantage which exists is an improvement in the load factor, which improvement but slightly affects the cost of production. It should further be remembered that the reduction in the cost is a reduction per unit, and may not necessarily mean an actual reduction in the total costs for giving a definite supply; that is to say, inasmuch as the generator has to supply units which are wasted in the battery, and is more or less evenly loaded, the load factor of the generating set is increased, and the number of units generated greater than if a battery were not installed. The curve shows that the reduction in the cost of generation with a 33 per cent. improvement in the load factor

is only 8 per cent., and that as the load factors are increased, the improvement due to the introduction of batteries reckoned as a percentage decreases to a point which becomes almost insignificant. Upon general grounds, therefore, the author is led to the conclusion that in moderate sized stations the advantages to be obtained from the use of batteries are not justified by the capital charges involved; and it may be well now to give some actual results in connection with two stations in which he is interested.

In the first station, which supplies current to a tramway system operating an average of 28 cars per day, and which in addition supplies approximately 1,000,000 units per annum for power purposes and for street lighting, the plant consists of two 500-k.w. 2-phase alternators, one 500-k.w. direct-current generator, and a battery having a capacity of 265 amperes for six hours. In addition to this, there is installed a motor-generator of a capacity of 250 k.w. for converting from alternating to direct current. It may here be remarked that the capacity of this station and the size of units are out of proportion to the load which has to be supplied, owing firstly to the fact that the station was designed to deal with a much larger load than at present exists; and secondly, to the necessity for the installation of different types of plant to supply a somewhat extended area. It is the practice in this station to run the alternator for the purpose of supplying high-tension current to the substation, and for driving the motor-generator as an alternating-current motor; the direct-current side of the motor-generator being in parallel with the battery. In this way, the alternating set is fairly well loaded, and the load is fairly steady. The motor-generator set is also practically fully loaded on the five week days, and comfortably copes with the direct current load. On Saturdays and Sundays, however, it is found impracticable to deal with the load with the one generating set, either with or without the battery, and on these days the 500-k.w. direct-current set is utilised in addition to the alternating-current generator, the sets on these occasions being loaded to about half their capacity. The generating sets have in each case an overloading capacity of 50 per cent., and the average steam consumption on test was found to be 21·22 lbs. per kilowatt-hour at full load; 23·423 lbs. at three-quarter load; and 25·22 lbs. at half load. From time to time tests have been made on the plant running under varying conditions, and the following results have been obtained.

The duration of the first test was 31 days: during 26 days the station was run without the battery, the direct-current machine being compounded, and during five days the station was run with the battery, the total output during the whole period being 196,448 units.

The second test also covered a period of 31 days, the total output being 195,510 units, and the plant being run for 26 days with the battery and five days without the battery. The costs of operation under these two conditions were as follows :—

	Test (1) without Battery. Cost per Unit generated. d.	Test (2) with Battery. Cost per Unit generated. d.
Coal	0·187	0·147
Water	0·032	0·032
Oil	0·029	0·017
Waste	0·003	0·003
Stores	0·009	0·006
Wages	0·220	0·217
	0·480	0·422

The coal consumptions during these tests were :—

	Test 1.	Test 2.
Per unit generated ...	5·519 lbs.	4·240 lbs.
„ sold	6·678 lbs.	5·324 lbs.

When running with the battery, the units lost amounted to 39,810, whilst when running without the battery the units unaccounted for were 36,467. The costs, therefore, per unit sold were 0·592d. without the battery and 0·533d. with the battery, or a difference of 0·059d. in favour of the battery, representing a total annual saving of £578 4s. 0d.

It might be contended that the necessity to run the two sets without the battery clearly indicates that the capital cost of the plant required for this supply could be reduced to the extent of one complete unit, and, of course, if this were so, the advantage to be derived from the installation of the battery would be absolutely and completely justified; but, as a matter of fact, this is not so. The one set could take care of the load under all conditions if the motor-generator had a larger capacity, but as it is, the motor-generator is incapable of overload, and although the single generating set is perfectly able to deal with the whole load, it is impracticable to operate the station in this way, as the motor-generator is unable to deal with its portion of the load. If the capacity of the motor-generator were increased to between 300 and 400 k.w., then the one set could quite easily take the whole load under both conditions. In another station with which the author was associated a 500-k.w. set was regularly used to supply current for 50 cars.

During last month a further test was made for a period of five days, running without the battery, the coal consumed being 4·779 lbs. per kilowatt-hour generated, and 5·262 lbs. per kilowatt-hour accounted for; whilst the coal consumption for the six months ending December, 1905, and running in the ordinary way with the battery, was 4·257 lbs. per kilowatt-hour generated and 5·101 lbs. of coal per kilowatt-hour accounted for. These later tests are particularly interesting as showing the difference between the coal consumption per unit generated and sold under the two conditions. When working without the battery, the difference is 0·483 lb., whilst when working with the battery the difference is 0·844 lb.; that is to say, without the battery there was practically a 10 per cent. loss and with the battery 20 per cent.; the result being that whilst there is a difference in coal consumption per

unit generated of 0·522 lb. per kilowatt-hour in favour of the battery, there is only a difference in the consumption per kilowatt accounted for of 0·161 lb. per kilowatt-hour. The actual reduction in cost, therefore, under these conditions is of the order of £55 per annum in favour of the battery.

As there appeared some likelihood of variation in the quality of the coal, further tests were made with and without the battery for periods of 12 hours each, and the steam consumption measured. The number of units generated when working with the battery was 4,600, and the units accounted for 4,273, the loss being 327 units; whilst the units generated when running without the battery were 4,380, the units accounted for 4,247, the loss being only 133 units. When running under these conditions, the steam used per kilowatt-hour generated was as follows :—

	With Battery.	Without Battery.
Units generated	30·434 lbs. ...	34·497 lbs.
Units sold	32·763 lbs. ...	35·578 lbs.

This test again indicates the same general result; the useful units supplied in each case are practically identical, whilst 220 extra units were generated when running with the battery. The difference between the steam used per kilowatt-hour generated, whilst being largely in favour of the battery, viz., 4·063 lbs. between the steam consumed per unit accounted for, it is decreased to 2·815 lbs., showing clearly the extra steam consumption due to the units generated and lost in the battery. Assuming 1 lb. of coal evaporates 7½ lbs. of water, and coal at 6s. 6d. per ton, the total annual saving when generating 2,500,000 units amounts to £136 2s. 8d., which is equivalent to 0·013d. per unit. It should be pointed out that, owing to the relation between the size of the units and the load with which they have to cope, the conditions obtaining in this station are about as favourable as they possibly could be for the battery. As already explained, when using the battery, one set is practically fully loaded, whilst without the battery the two sets are loaded only to an average of from one-third to one-half their rated capacity.

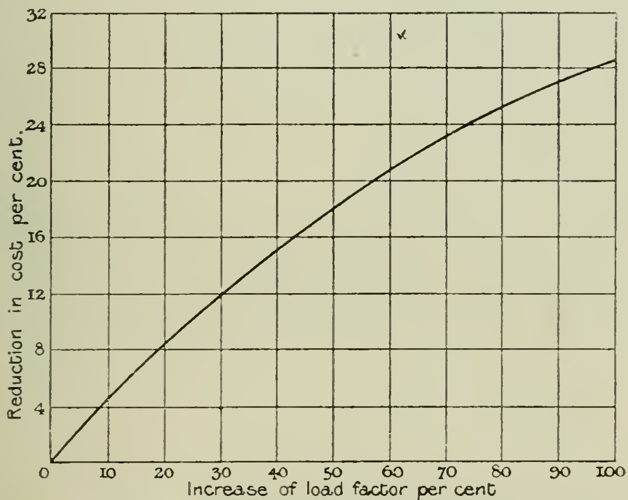
Let us now ascertain at what cost the reduction in the working costs due to the battery, above enumerated, is obtained. The following is a statement of the capital cost of the battery with its equipment of boosters, etc. :—

Battery	£3,546
56-k.w. positive booster	729
40-k.w. battery booster with Thury regulator ...	1,849
240-ampere milking booster	50
Switch-gear	300
Buildings	750
Connections	50
Total ...	£7,274

The annual capital charges involved in connection with this equipment are as follows :—

	£	s.	d.
Interest on cost of buildings, boosters, etc., 5 per cent. on £3,728	186	0	0
Depreciation on ditto, 2½ per cent. on £3,728	93	0	0
Interest and sinking fund on battery, 6 per cent. on £3,546...	212	15	0
Maintenance (annual amount contracted for in tender)	236	0	0
	£727	15	0

representing a cost per unit of 0·07d., whilst the reduction in cost due to that equipment under the best possible conditions is only 0·059d. per unit, and on the later steam consumption tests only 0·013d. per unit.



Curve showing Reduction in Cost per Increase of Load Factor.

In the second case which came under the author's notice the station is a combined lighting and power station equipped with two 125-k.w. sets, two 215-k.w. sets, and two 330-k.w. sets ; the total capacity of the station being 1,340 kilowatts. The units generated for the year were 2,397,237, the traction supply taking 1,387,279, the lighting and power supply 659,527 units, the difference between the units sold and the units generated being 303,354. In this station the traction battery has a capacity of 250 k.w. for one hour. The supply is given from this station to the tramways under an agreement by which the tramway authorities pay the actual cost of generation, and in addition 10 per cent. on the capital cost of the plant to cover interest and sinking fund charges and depreciation. Now the plant upon which the tramway authority pays these capital charges is taken to be the two 125-k.w.

sets, one of the 215-k.w. sets, and the battery. The capital cost of the steam-raising plant is £13,307, and the capital cost of the batteries approximately £3,000. From the tramway undertakers' point of view, there is little or nothing to take exception to in regard to the capital cost of the plant upon which they are charged. It has been claimed that the installation of the battery and booster system at this station has resulted in a lower capital expenditure on generating plant, and in reducing the works costs, and although the tramway authority cannot complain of the amount charged to them in respect to the capital cost of the plant, it is curious to note that whilst they are only debited with generating plant of a capacity of 465 kilowatts, the lighting and power supply is debited with 875 kilowatts, whereas the maximum load upon the tramway part of the undertaking was 500 k.w. and upon the lighting undertaking 400 k.w.

It would therefore appear that, in order to justify the capital expended on the installation of the batteries, it has become necessary to debit the lighting portion of the undertaking with a much greater proportion of the total plant capacity of the station, although the maximum demand is actually less than the maximum demand upon the tramways. If the tramway authority had been charged on the plant capacity in proportion to the load, they would have been in a position to dispute the cost of the battery installation as not being "reasonably" necessary. There is little doubt that plant capable of dealing with this tramway supply, which has an average of twenty-four cars running, could be erected for £16,000, excluding buildings, which is practically the amount now charged.

Turning now to the costs of generation, the following is a statement of the actual works costs as charged to the tramways :—

	d.
Fuel	0·22
Oil, waste, and water	0·03
Repairs	0·15
Wages	0·34

It should be remarked, however, that the wages item is only charged to the tramway supply up to 800,000 units, it being assumed that the wages and management charges are "fixed," and that any additional supply is given at the rate of 0·37d. per unit to cover the cost for fuel, water, and repairs, which items are considered proportional to the output. It is, of course, impossible for the author to say what would have been the result of working if the battery had not been installed, and he can only show what the capital charges involved in connection with the provision of the battery system amount to, viz., £557 10s. per annum, made up as follows :—

	£	s.	d.
10 per cent. on capital cost of batteries—£3,000 ...	300	0	0
Maintenance	167	10	0
Interest on capital cost of buildings	90	0	0
	£557	10	0

and he points out that these charges are equivalent to 0·096d. per unit If the battery system had not been installed, the working costs could have been increased to 0·466d. per unit and the same result obtained. There is not the slightest reason to suppose that if the battery had not been installed the cost could have been so much higher (over 25 per cent.). The coal consumption per unit generated is now assumed to be 4·73 lbs., whilst per unit sold it amounts to approximately 5·3 lbs.

These results are almost precisely similar to the results obtained by the author in his own station on the later tests when working without the battery, and if allowance is made for the capital charges involved in the provision of the battery system, they are practically equivalent to the results of the first test made under conditions so favourable to the battery.

It would therefore appear that the conclusion, deduced from a general consideration of the matter, that the advantages to be gained by the installation of storage batteries, in tramway and power stations of even moderate size, are not justified by the cost at which they are obtained is well borne out by the actual results obtained under test at the author's own station, and also by the results obtained in actual practice in another station where batteries were specially introduced to obtain these advantages. In such an attractive form have those advantages been proclaimed that batteries of accumulators have been installed without any regard to the cost at which the advantages were obtained, and the author hopes that results of other tests may be forthcoming to assist in the determination as to whether it is not more economical to provide generating plant of such a character as to meet the conditions of electric supply as they now exist than to install batteries of accumulators involving capital and maintenance charges out of proportion to the advantages to be derived therefrom.

DISCUSSION.

Mr. S. L. PEARCE: There has been a tendency to put forward storage batteries as a panacea for all ills, and as applicable in each and every case, whether dealing with lighting, traction, or mixed systems, and I think good would be done if this paper of Mr. Salter's induced engineers to think out each case on its own merits and carefully weigh up the merits and demerits of installing storage batteries in connection with their systems. Mr. Pearce.

Mr. THOS. L. MILLER: I agree with a very great deal that the author has said with regard to batteries, but I am not prepared to go to the full extent of his condemnation of them. In large tramway or lighting stations I agree that the battery is of doubtful value, but in small lighting and tramway stations the battery has a distinct field, and one in which its adoption is the means of effecting considerable economy. Before saying more, however, I would like to refer to the question of maintenance agreements which has been raised by the previous speaker. Unfortunately, my experience of maintenance agreements has not been satisfactory; some battery makers are only too willing to Mr. Miller.

Mr. Miller. enter into such maintenance agreements, and while the battery is in order, and the premiums are regularly paid, everything goes on smoothly. When, however, anything goes wrong with the battery it is only too frequently the case that the maker attempts to take advantage of some obscure clause in the agreement for the purpose of evading his liabilities under such agreement. In two cases in which maintenance agreements had been entered into with large public bodies, the battery company cancelled these agreements because, owing to an error on the part of one of the clerical staff, the premiums had not been paid on the date stipulated in the agreement. In another case it was pointed out that the battery had been discharged beyond the stipulated limit, although the rate of discharge was only one-half of the specified rate for the given capacity. Other cases may be cited where I cannot help saying that some battery makers take an unfair advantage of their clients in the interpretation of the maintenance agreements, and until battery makers are prepared to treat their customers in a reasonable way, I think those having to advise with regard to battery agreements will be very chary indeed of entering into them.

With regard to the use of batteries in small tramway stations, I consider that in small stations, dealing with up to, say, forty cars, batteries are extremely useful, and tend to economical working. In the case of one town I have had to do with about thirty to thirty-five cars were in use on the system at times of heavy demand, and a battery and a reversible booster were installed in the station. During the period of light loads one 100-k.w. set with the battery and reversible booster was found to be sufficient to supply the energy for running the cars, whereas without the battery and booster the demand required two 100-k.w. sets to be run at about 80 per cent. full load. At busy times, when the full number of cars was running, the load was taken by two 100-k.w. sets, with the battery and booster, the total output being 380 k.w., so that had the battery not been installed four 100-k.w. sets would have been required to deal with the load. In cases like the one referred to, the installation of a battery and booster is of great assistance and reduces the amount of generating plant required.

In another case power was purchased in bulk from a supply company, the maximum demand being stipulated not to exceed 400 amperes. A battery and reversible booster were installed, and although at times 700 amperes were demanded, the stipulated rate of 400 amperes from the supply company's mains was not exceeded.

Mr. Salter, in his paper, makes comparison between the life of a battery on a lighting and on a traction system. This, I think, is unfair, as in the former case the battery is far more severely punished than in the latter, where the battery is kept fully charged during the whole period and practically floating on the load.

Mr. McKinnon. Mr. McKinnon: I do not consider Mr. Salter's station well designed. Accumulator companies are prepared to keep batteries up to 100 per cent. efficiency at an annual charge of 6 per cent. I consider that Mr. Salter's contention that batteries are not to be compared to the cost of generating machinery is without any sort of justification, because on

that ground, in the case of breakdown with generating plant, one would judge him to be just as well satisfied with a motor-generator as with a battery, and one knows very well that such would not be the case. I have studied the figures given in reference to Mr. Salter's works, and consider the capital cost is greater than necessary. I would like to add, in the face of his statements, that we have fitted up 300 battery booster installations in the United States during the past year. Mr. McKinnon.

Mr. C. D. TAITE: The author has dealt with an interesting and important problem. He appears, however, to have fallen into the error of generalising on insufficient data. There are few problems which require so much individual consideration as those connected with the size and scope of batteries; the decision in each case depends entirely upon the local conditions. It does not at all follow that what is good for one town is equally satisfactory for another of the same size; the effect of the load factor, cost of fuel, and the momentary variations in the load are all features which have an important bearing on the utility of battery plants. Mr. Salter has taken exception to the custom of comparing the cost of a battery with the cost of generating plant which the provision of a battery enables one to dispense with; but surely there is no valid argument against comparing the cost of a plant designed to deal with a certain load and equipped with a suitable battery with the cost of a plant designed to deal with the same load, but without storage plant; the purchasers of the plant must have definite figures setting forth the relative advantages from the financial point of view of the two systems; otherwise, how are they to come to any decision on the subject? Mr. Taite.

The author has endeavoured to show that the economy in running expenses due to the use of a battery does not compensate for the latter's maintenance charges, but he appears to have entirely overlooked the numerous advantages possessed by a battery, for which it is difficult, however, to give a monetary value; on all but the largest systems a battery enables the generating plant to be shut down nightly for some hours, and on Sundays for quite long periods, thus not only saving wages, but permitting repairs to be conveniently carried out. The improvement of the load factor is an important matter, particularly on small tramway systems; and the experience of the L. & Y. Railway Company seems to show that for fairly large railway systems batteries are a great boon. Again, in case of short-circuits the reserve of power in a battery is very useful for burning out faults, and its capacity for tiding over some unexpected trouble in the generating station is invaluable on such occasions.

Of course, we all wish that batteries were cheaper and more efficient, but even in their present state I hold that the advantages which they offer are in most cases very appreciable, and it must not be overlooked that maintenance rates can now be obtained which reduce the cost of upkeep of a battery to a percentage rate no greater than that necessary for the generating plant itself.

Mr. E. S. JACOB (*communicated*): The most interesting portion of Mr. Jacob.

Mr. Jacob. the paper is the test made by the author by running with and without the battery, as such tests can be very rarely made. Though the figures of economy in coal consumption are certainly accurate, the remainder of the calculations are open to criticism. The annual saving depends on the cost of coal, in respect of which the works where the tests were made are admirably situated.

At the present day the capital expenditure could be revised, and might be fairly estimated, I think, under present conditions, at the following figures, which allow a very reasonable margin :—

Battery	£2,800
Positive booster	729
Battery booster	600
Milking booster	50
Switch-gear	200
Building	750
Connections	50
Total	£5,179

The revised annual charges will then be :—

Interest on building, boosters, etc., 5 per cent. on £2,379	£119
Depreciation on building, boosters, etc., 2½ per cent. on £2,379	60
Interest and sinking fund on battery, 6 per cent. on £2,800	168
Maintenance (from first charge)	181
	£528

The saving in running costs shown by the author was £578, and thus, instead of a net loss of £150, there will be a net saving of £50 per annum even with coal at such a low price as 6s. 6d. per ton ; for every additional shilling in the price of coal the economy will be increased by about £30. No details of the load curve or the variations are given, and judging from the number of cars running I should think that the battery is much larger than is required to take up the peaks ; it is certainly more than large enough for the night load, as it is sufficient for present purposes with only 55 per cent. of the capacity it would have had had the amount allowed for maintenance been spent on it. This is a most important point, as the whole question of economy must depend on whether the battery plant is of suitable size, and any reduction in capital outlay causes a corresponding reduction in the annual charges, which, judging from the particulars given, may be equivalent to a further annual saving of £200.

In regard to the author's remarks that the loss with the battery is 20 per cent. of the units generated, while without the battery it is only 10 per cent., it seems that while in the latter case alternating as well as

direct current is generated, in the former case direct current only is generated, and the loss in the motor-generator when converting from direct to alternating current may be the cause of a good part of the extra loss that is noticed when using the battery. This fact can be set against the disadvantage mentioned, that when running without the battery there are not sufficient cars to load the engine fully. Mr. Jacob.

Mr. J. R. SALTER (*in reply*): None of the contributors to the discussion appear to have brought forward actual figures to throw light upon the subject of the paper. I did not wish to imply by any means that batteries are not "useful," but what I desired to ascertain was whether the advantages to be derived from their use are justified by the cost at which they are obtained. Mr. Miller gives one instance where he claims to have obtained some advantage from the employment of batteries, but here again he gives no idea as to the cost at which he has obtained those advantages. It would appear that, in the case referred to, although on occasions the load can be dealt with by one 100-k.w. set, and on other occasions by two such sets, the total capacity of the generating plant installed has not been actually reduced by reason of the installation of the batteries. If this is so, no saving in capital cost has been obtained, but, on the other hand, an extra cost has been incurred for the provision of the battery; and the sole benefit has been an improvement in the load factor. The money value of this advantage is fully dealt with in the paper. In the other instance quoted by Mr. Miller, where the supply was obtained from a power company, the installation of a battery might certainly be justified, but this justification is of an incidental character, and is due to the fact that the price charged by the power company referred to depends upon the individual maximum demand, and does not take into consideration the diversity factor. This latter factor ought to be taken into consideration by the power company, if they desire to make their charges for a given supply bear the proper relation to the cost of giving that supply. Mr. Salter.

Mr. McKinnon's remark as to the design of the station is quite gratuitous, as I admit that the station was designed to deal with a very much larger load than existed at the time the tests were made; but the conditions then obtaining were actually in favour of the battery, as the generating sets were much too large to deal with the load *without* the battery, and consequently were running at from one-third to half of their rated capacity, and with lower efficiency. I certainly do not consider that the battery is worth anything in the case of a breakdown on a tramway or power system. The most ardent advocates for the employment of storage batteries do not recommend the installation of batteries of such a capacity as to be capable of taking the whole load for any appreciable time.

Mr. Taite's remarks as to my objection to the comparison of the capital cost of a battery with that of steam-raising plant are so fully dealt with in the paper that nothing further remains to be said, except that I still fail to appreciate a comparison which involves the introduction of a time element in one case, and not in the other. I certainly overlooked the advantage claimed for the battery as a burner out of faults.

Mr. Salter.

Mr. Jacob's figures given in his later communication are interesting, and are directed more to the subject of the paper than are the other criticisms. The best result, however, which Mr. Jacob can obtain, and this by reducing the capacity and the capital cost of the battery, is to effect a saving of £578 in the running costs, for which he pays £528 in capital charges upon the battery. In the other tests which I carried out the actual saving in running costs amounted to £55 and £136 respectively, so that, taking the latter figure, there is still an annual loss of something like £400 due to the employment of storage batteries. Of course, it is quite possible to reduce the capital cost by reducing the capacity of the battery, but if the battery is to maintain its output for ten years, the maintenance charges involved would be very seriously increased. In other words, the lower the capital cost of a battery for a given capacity at the end of a long period, the greater will the maintenance charges be to keep the battery up to its capacity.

MANCHESTER LOCAL SECTION.

LIFTS AND HOISTS.

By H. C. Crews, Member.

(*Abstract of Paper read April* 10, 1906.)

This subject embraces an extensive and very debatable matter, but the limited time at disposal only allows a portion to be dealt with —more in a commercial than a technical manner. Sufficient practical details, however, are included to form a basis for discussion.

In Manchester and Salford alone, the Corporation mains at present supply current to over 200 highly economical electric lifts or hoists, apart from cranes, jibs, teagles, etc. Private electric plants in the town also provide energy for an additional number. On the other hand, this and other enlightened cities still foster hundreds of busy hydraulic lifts and hoists using as much energy to take the attendant alone up to the top floor as to lift 5 to 30 cwts. of useful load the same distance.

For purposes of this paper, the term "lift" is used generally to denote the most usual, moderate speed, passenger machine. The term "hoist" is used to denote a similar, somewhat slower and rougher, cage goods machine. Normal full loads vary from 6 to 15 cwts. respectively, in all lifts and hoists referred to. With one exception, high-speed machines are not referred to, because at the present time they find but little favour in this country. The tendency of local users is, in fact, rather towards slower speeds than modern hydraulic equipments have accustomed us to.

There are only six public high-pressure hydraulic supplies in this country—London, Manchester, Liverpool, Glasgow, Birmingham, and Hull—with working pressures varying from 700 to 1,000 lbs. per square inch. There are, on the other hand, some 400 public electric supplies with a cheap power rate available for lift or hoist work at 400–500 volts pressure. Thus electrical engineers in this country have opportunities at least, in the ratio of 400 to 6, of competing successfully with hydraulic engineers for the most economical types of each equipment.

Hydraulic Types Investigated.

A.—High-pressure, suspended, passenger.
Variable power, two rams, balanced.

B.—High-pressure, suspended, passenger.
Single ram, balanced.

C.—High-pressure, direct ram, passenger.
Hydraulic cylinder balance.

D.—Low-pressure, suspended, passenger.
Top and bottom open tanks and pump.

E.—Low-pressure, direct ram, passenger.
Ordinary weight balance.

F.—High-pressure, suspended, goods.
Single ram, balanced.

Electric Types Investigated.

P.B. (Push Button).—Suspended, passenger. Direct worm gear.
Top or bottom, drum or sheave, drive.
Full automatic push-button control.

T.D.(s) (Top Drive).—Suspended, passenger. Direct worm gear.
Drum or sheave drive. Car switch control.

T.D.(r) (Top Drive).—Suspended passenger. Direct worm gear.
Drum or Sheave drive. Hand-rope control.

B.D. (Bottom Drive).—Suspended, passenger. Direct worm gear.
Drum or sheave drive. Car switch or hand-rope control.

G.E. (Goods, Electric).—Suspended, goods. Direct worm gear.
Drum or sheave top drive. Hand-rope control.

P.E. (Power Electric).—Suspended, light goods. Single spur gear.
Top sheave drive. Belt-driven from continuous-running motor.

A few hydraulic lifts have recently been fitted with a press-button system of control. Private hydraulic accumulators are occasionally included in lift installations for increasing domestic water to high pressures. Pneumatic tanks with pumps, for increasing low-pressure water to moderate pressures, are also sometimes adopted for similar purposes. Excessive capital charges, or absence of simplicity with consequent high maintenance costs, however, rarely give them any chance in a commercial or economical comparison where other types —either hydraulic or electric—are possible.

Full investigations and tests have recently been made, purposely for this paper, on an equal number of actual hydraulic and electric lifts or hoists, as to general particulars, energy, and maintenance details, total costs, etc. All tests have been taken during ordinary working hours and with machines under normal—not specially prepared—conditions. Nine hydraulic lifts and three hoists in all are tabulated ; nine existing

machines, and three lifts which nearly a year ago were each adapted to electric working. These adapted machines were all first-class, and by no means out-of-date, examples. No. 1, a high-pressure direct ram with hydraulic balance, built three years ago by a leading firm; Nos. 3 and 7, both high-pressure fully automatic, variable-power lifts, by one of the most experienced first-class makers. That such machines are still among the most efficient hydraulic types is shown by the comparatively good performances of the two types in existing examples, Nos. 2 and 5. Other actual hydraulic machines tabulated are claimed as being generally fair average samples of their respective classes. Bad local conditions, indirect drives, high gear ratios, or obsolete patterns have been avoided.

Some very favourable hydraulic examples have, on the other hand, been included. Nos. 1 and 12, for instance, are debited with energy at a very cheap rate, on the usual sliding-scale method of charge, by sharing supply with other hydraulic machines requiring considerable power. In example No. 2 £20 per annum has been deducted from the actual energy bill, as credit for spent water used in the same building for ordinary domestic purposes. Low-pressure water for such service would average £20 cost per annum from the ordinary town mains. This arrangement is not, however, as advantageous as might at first glance be supposed, because, apart from a little balance loss in lift, the necessary capital outlay on extra piping and tanks is usually considerable in adopting such a scheme.

Although No. 10 is not a busy hoist, yet it is one of the best examples of a modern machine. The poor average load of No. 11 example is quite typical of numerous goods hoists, which are also used for private passenger work—a frequent condition in works, warehouses, etc. It would be difficult to find two more economical cases of low-pressure hydraulic lifts than Nos. 8 and 9. No. 8 has its spent water raised over and over again by a modern and economical electric pump, run only when necessary, and controlled by a tank float arrangement. No. 9 works out, in a rather deceptive manner, as one of the cheapest hydraulic examples in total annual costs tables. This is almost entirely due to the fact that it shares its water supply with *several* other large machines, and thus obtains ordinary domestic water at about half the usual large town rate for quantity actually consumed. Wages chargeable to these low-pressure examples are, from force of circumstances, also much below average of all examples taken. It is sometimes stated in a general sort of way, by interested persons, that electric lifts cost nearly double hydraulic ones, but in the examples tabulated it will be noted that there is little average difference at all with fair proportions of all usual types included. The hydraulic examples taken were manufactured by six different leading firms.

The number of electric lifts not connected with public supplies is quite small, and all electric examples included in this paper are, therefore, merely of usual types suitable for such connection.

Nine electric lifts and three hoists have been also taken almost at random—only as in hydraulic examples avoiding bad local conditions.

They are doing the same class of work, and in Table II. each is placed opposite the nearest similar hydraulic machine given in Table I. Nos. 21, 23 and 27 are Nos. 1, 3 and 7 respectively adapted to electric working. Corresponding speeds have not been possible for every pair, but excepting No. 1—which was quite abnormal in speed —it may be noted that total average speeds of both equipments are identical.

TABLE I.

General Particulars (Hydraulic Examples).

Actual Example No.	Type.	Approx. Prime Cost, 1906 Prices.	Rated Full Load in Cwts.	Actual Full Travel in Feet.	Average Speed in Ft. per Min.	Annual Duty in 100,000 Ft.-Cwts.
1*	C	£500	10	69	315	176
2	A	£460	9	84	190	91
3*	A	£270	7	62	170	74
4	B	£260	6	43	168	33
5	C	£500	10	38·2	160	75
6	B	£180	7	55	160	29
7*	A	£250	7	44	120	48
8	D	£500	8	35·2	85	20
9	E	£320	9	46·5	42	27
10	F	£250	15	53·5	172	22
11	F	£200	12	59	139	37
12	F	£150	15	59	120	72
Average ...		£320	9·5 cwts.	54 ft.	153	58

* Now Nos. 21, 23 and 27 respectively, adapted to Electric Working.

As practically two each, of the six electrical types scheduled, are included, it is obvious that at suitable speeds there was locally but little choice of specially efficient electrical examples. These are included much in the proportion in which they actually exist throughout the country, as in the case of hydraulic examples taken.

All particulars affecting cost or efficiency of examples have been scheduled, in various tables following, much in accordance with their

respective bearing on the particular table concerned. Thus a fair overall comparison is possible of what can be, and really is being, done to-day, not in special or hypothetical cases, but under the various actual and usual conditions of everyday use. For obvious reasons the actual locality and ownership of the various lifts referred to cannot be stated here. All the machines, except the three hydraulic ones recently adapted, are, however, working to-day in well-known positions and

TABLE II.

General Particulars (Electric Examples).

Actual Example. No.	Type.	Approx. Prime Cost, 1906 Prices.	Rated Full Load in Cwts.	Actual Full Travel in Feet.	Average Speed in Ft. per Min.	Annual Duty in 100,000 Ft.-Cwts.
21*	BD	£350	7	69	210	176
22	TD(*s*)	£375	12	53·5	170	315
23*	TD(*s*)	£350	7	62	190	74
24	BD	£375	7	36	155	74
25	BD	£400	7	59	155	68
26	PB	£380	7	35	86	33
27*	TD(*r*)	£300	7	44	160	48
28	PB	£450	7	21	100	3
29	TD(*r*)	£300	7	46·5	126	7
30	GE	£220	15	45	105	36
31	PE	£160	7	42	95	90
32	GE	£250	15	45	60	74
Average ...		£326	8·7 cwts.	46·5 ft.	134	83

* Formerly Nos. 1, 3 and 7 Hydraulic Examples respectively.

are owned by prominent business individuals or public companies in the Manchester, Liverpool, and North Wales districts. The electric examples taken were, as in the case of hydraulic examples, manufactured by six different leading firms.

Prime costs of all examples are taken at to-day's prices, based on recent actual quotations from respective makers. A considerable proportion of total first cost when installing a lift or hoist of any type

is often due to structural causes, particular ideas as to safety gates, ornamentation of cage, enclosures, etc. Prime cost values scheduled are, therefore, exclusive of all building work or enclosures, but otherwise they include reliable equipments with ordinary cages, safety gears, and everything necessary, fixed complete under moderately straightforward conditions.

TABLE III.

Energy Details, Etc. (Hydraulic Examples).

Actual Example. No.	Floors Served.	Average Ft. run per Single Trip.	Load Factor.	1,000 Ft.-Cwts. obtained per 100 Gallons.	Average Price per 100 Gallons (d.).	Energy Cost per 100,000 Ft.-Cwts. (£).
1	3	42	0·20	3·0	3·4	0·46
2	8	40	0·14	2·5	3·7	0·67
3	6	29	0·25	4·0	6·1	0·63
4	4	38	0·16	2·7	7·1	1·08
5	4	34	0·28	3·4	6·0	0·73
6	6	30	0·23	1·8	6·5	1·54
7	5	27	0·28	5·6	7·6	0·57
8	4	29	0·25	0·04*	0·13*	1·28
9	4	30	0·33	0·20*	0·68*	1·25
10	6	23	0·28	5·1	9·8	0·70
11	6	30	0·08	1·6	5·9	1·50
12	6	35	0·33	7·4	6·4	0·36
Average ...		32 ft.	0·23	3·7	6·2d.	£0·89

* Low Pressure, not included in totals of these two columns averaged.

Speed has been expressed in average, not maximum, feet per minute. Such average speed includes starts and stops on all usual trips demanded in each particular case. This at first sight makes examples generally appear below usual speeds. It must, therefore, be remembered that the short trip hoist would appear as a faster one with longer trips demanded. Actual times were taken with a stop watch from all first to last movements of cages. A lift with a good, steady acceleration may for short travel work really be more expe-

ditious in use than one with worse acceleration and higher maximum speed. In fact, the standard *maximum* speed used in lift work is rather misleading, although it may be easier to estimate beforehand. For instance, a lift rated at 230 ft. per minute was found to be doing daily work actually required at average speed of only 172 ft. per minute, with pressure, lubrication, etc., normal. For the full travel the rated speed was correctly marked, but rarely used.

TABLE IV.

ENERGY DETAILS, ETC. (ELECTRIC EXAMPLES).

Actual Example. No.	Floors Served.	Average Ft. run per Single Trip.	Load Factor.	1,000 Ft.-Cwts. obtained per B.O.T. Unit.	Average Price per B.O.T. Unit.	Energy Cost per 100,000 Ft.-Cwts. (£).
21	3	42	0·28	7·5	$1\frac{7}{8}$d.	0·10
22	5	25	0·29	7·8	$1\frac{7}{8}$d.	0·10
23	6	29	0·25	3·9	$1\frac{7}{8}$d.	0·20
24	4	27	0·28	3·9	$1\frac{7}{8}$d.	0·20
25	6	37	0·25	6·6	$1\frac{7}{8}$d.	0·13
26	4	24	0·28	4·0	$1\frac{7}{8}$d.	0·19
27	5	27	0·28	4·3	$1\frac{7}{8}$d.	0·17
28	3	16	0·24	5·4	$1\frac{7}{8}$d.	0·16
29	4	28	0·35	6·7	$1\frac{7}{8}$d.	0·11
30	5	29	0·20	8·7	1d.	0·04
31	5	32	0·28	3·4	$1\frac{1}{8}$d.	0·15
32	5	26	0·11	8·4	$1\frac{7}{8}$d.	0·09
Average ...		28 ft.	0·25	5·8	1·739d.	£0·13

The author has made comparisons of lift duties with a formula including a speed element, but thinks it better, for commercial reasons, on this occasion merely to adopt *nett foot-cwts. actually demanded* as useful work—both up and down—tabulating separately average speed at which such work is done and other essential conditions. Horse-power does not adapt itself very well for expressing duty of lifts, and only complicates calculations.

For purposes of comparison in all cases the weight of lift attendant has been ignored. He should be considered part of the balance load,

and more or less counterweight arranged accordingly. No *useful* load is worked in taking an attendant alone up or down. All weights mentioned, therefore, in this paper, except full load ratings, are nett (unbalanced). This method also allows of fair comparisons with press-button equipments.

Calculations are, as a rule, only made to slide-rule accuracy, or the nearest decimal place. Hydraulic and electric energy have been measured by the respective public supply meters in each example taken.

The fact which has been impressed on the author more than anything is the very small proportionate average nett load demanded in all single trips of most lifts and hoists. The ratio of average nett to full-rated (unbalanced) load, it may perhaps be permissible to refer to as load factor, not including the time element so important to station engineers and others. Including all raising and lowering trips, such a load factor averages rather less than one quarter; or in raising only, approximately one-third of full load in the twenty-four examples given. With an increased number of hoists, or larger lifts, included, these fractions would probably be still smaller and relatively more advantageous to electric equipments. This unavoidable condition of working is—more than has yet been generally realised—one of the chief causes of electric working being nearly always so much cheaper than hydraulic.

Electrical energy in all examples averages less than one-sixth cost of all high-pressure hydraulic energy per 100,000 ft.-cwts. of duty as defined. The single ram hydraulic lift for its usual average, quarter to third, load condition, always consumes full load energy. The electric lift only requires energy in proportion to the actual load each single trip. Another important factor affecting economy is the one more generally realised—*i.e.*, the extra counterweighting which it is practicable to adopt in electric equipments, with motor driving, when necessary, both for down as well as up journeys.

Small, or even moderate, quantities of high-pressure water are, as a rule, very much dearer relatively than equal electrical energy. Minimum charges per annum, including meter charges, for high-pressure water also vary from £10 to £6, as against £3 to nil, for electrical energy.

A 30s. minimum charge is avoided in the quiet electrical examples Nos. 28 and 29 by consumption of above that cost in lighting current on same premises.

"Duty obtained per 100 gallons" or "Energy cost per 100,000 ft.-cwts." demanded, at a particular speed, are in similar hydraulic equipments, it should be noted, merely questions of load factor and average price paid per gallon. Cost of power water has been tabulated in 100, instead of the more familiar 1,000, gallons, to form a nearer basis of comparison with the unit of electricity. The average 100 gallons in high-pressure examples costs 6·2d., and gives 3,710 ft.-cwts. duty. The average electric unit in examples costs 1·739d. and gives 5,800 duty—more than five times cheaper results from this point of

view. Whereas other machines on the same meter reduce relative cost of high-pressure water, similar conditions usually effect equal economy on electric supply. Hoists Nos. 30 and 31 are examples of this latter fact, balancing the cheaper water-power of Nos. 1 and 12 hydraulic machines.

"Average feet run per single trip" is unimportant in hydraulic work, but a most important consideration in electric working, which should not be overlooked in comparing energy efficiency of various lifts. More electrical energy is used in overcoming inertia and accelerating many journeys than for the remainder of even fairly long trips. A careless attendant may, owing to this fact, waste considerable electrical energy per annum, by not stopping accurately at floors and having to re-start the motor frequently for short re-adjustments of cage level. This fault is often overlooked. Attendants—particularly those used to hydraulic—when put to work electric lifts, are also seldom made thoroughly aware of the fact that some energy is consumed on down as well as up journeys, and that this is greater with the cage descending empty than with the average load. Thus premature down journeys are often made by the attendant with an empty cage, instead of waiting, when possible, for some load to assist the starting effort of the motor.

If the electric lift or hoist counterweight is carefully proportioned to the actual average gross load, instead of the more usual method of always balancing half-rated full load plus cage, etc., irrespective of actual carrying conditions demanded, a rather poor load factor has not in itself very much effect on energy efficiency of an electric equipment.

"Duty obtained per unit of electricity" is dependent mainly on efficiency of gear with similar speed, weight, drive and load factors. Safe self-sustaining conditions are sometimes for this reason sacrificed to efficiency in worm gear, without sufficient brake control. In the author's opinion, if higher efficiency gear is generally adopted by makers in this country for busy electric lifts, a second brake will become imperative. Possibly a modified power band brake, acting on an extension flange of large diameter overhead sheave, and arranged for mechanical operation from cage in case of emergency, may ultimately be adopted, with an 85 per cent. efficiency worm gear, in addition to usual electric brake.

Recent power rate reductions on public electric supplies, notably St. Pancras Borough and Westminster Electric Supply Company, London, are very advantageous to users of electric lifts, and much more than compensate for reductions or prospective reductions on any public high-pressure hydraulic supplies. The entire tendency of public supply electric power rates in large towns is towards a general one penny per unit charge. Public hydraulic supplies having no equivalent of a lighting or night load to assist costs will probably soon be unable to compete at all successfully for lift and hoist energy.

Energy costs of electric examples include, in a few cases, current for the cage light, and in some machines this will amount to over £1

per annum. No hydraulic example is, however, saddled with such a charge.

Maintenance cost is more a question of local conditions, attention received, drive, speed, and duty than whether hydraulic or electric equipment is adopted. The class of any lift, of course, also enters largely into this question. Thus the relatively cheap hydraulic machine exemplified in No. 6 is much more expensive to maintain

TABLE V.

MAINTENANCE DETAILS (HYDRAULIC EXAMPLES).

Actual Example. No.	Gear Ratio.	Age.	Thousand Single Trips per Annum.	Rope Cost or Allowance per Annum (£).	Repairs, Stores, and Inspections per Annum (£).	Maintenance Total (£) per 100,000 Ft.-Cwts.
1	(Ram)	2	209	—	12·0	0·06
2	4 : 1	9	194	6·7	10·0	0·18
3	4 : 1	7	139	3·0	2·0	0·06
4	4 : 1	10	68	1·8	16·2	0·54
5	(Ram)	11	71	—	10·0	0·13
6	6 : 1	7	61	2·0	10·2	0·42
7	4 : 1	8	88	2·5	10·0	0·26
8	2 : 1	10	39	4·0	5·0	0·45
9	(Ram)	15	30	—	5·0	0·18
10	4 : 1	2	22	2·5	2·5	0·22
11	6 : 1	6	124	1·5	8·0	0·25
12	4 : 1	7	41	1·5	6·0	0·10
Average		7	90	£2·8	£8	£0·23

than the dearer high-class one exemplified in No. 10. There are at present so few electric lifts over which, say, seven years' average experience of actual maintenance costs can be obtained—as in the case of hydraulic examples—that no definite general assertion can be made regarding the former by any one with absolute certainty. It will be seen, however, that over an average of three years' experience in examples given, electric equipments show some advantage in this respect also. Actual maintenances on the two oldest electric machines, Nos. 29 and

31, are relatively better than most costs, partly estimated, for the newer equipments included.

The kind of drive adopted enters very largely into the maintenance cost of any suspended type. For electric lifts, whenever local conditions allow the adoption of a top-drive requiring only one sheave, and if this is of large diameter, having properly designed V-grooves, there is no doubt that rope renewals are a minimum, and cost less for

TABLE VI.

MAINTENANCE DETAILS (ELECTRIC EXAMPLES).

Actual Example. No.	Drive.	Age.	Thousand Single Trips per Annum.	Rope Cost or Allowance per Annum (£).	Repairs, Stores, and Inspections per Annum (£).	Maintenance Total (£) per 100,000 Ft.-Cwts.
21	V Sheave	1	209	4·0	2·5	0·03
22	Sheave S	2	360	8·0	29·0	0·11
23	V Sheave	1	139	2·0	2·0	0·05
24	Sheave S	3	145	3·0	7·2	0·13
25	V Sheave	5	104	7·0	3·3	0·15
26	Sheave	1	70	2·0	8·0	0·30
27	V Sheave	1	88	2·0	6·0	0·16
28	Drum	3	13	1·0	1·0	0·66
29	V Sheave	6	10	1·0	1·0	0·28
30	V Sheave	1	42	0·5	3·0	0·09
31	Belt	9	140	0·5	1·7	0·02
32	Drum	3	40	4·4	8·0	0·16
Average		3	113	£2·9	£6·0	£0·18

equal duty than with any hydraulic suspended arrangements. The latter, with their numerous bends round multiplying sheaves, and often a damp well, have clearly worse conditions for steel ropes than average electric equipments entail, even allowing for U-grooves against V ones in sheaves.

If, however, for structural reasons, accessibility of motor, etc., or slightly steadier working, a bottom electric drive is adopted, rope costs are usually but little better than hydraulic figures. One often hears a

general sort of statement made that the average life of ropes should be so long—three to four years seems a favourite period. Apart from drive adopted and local conditions, the amount of work a lift is doing, and the speed at which such work is being done, are, as a rule, overlooked in such general statements. Thus the figure scheduled for example No. 22 may appear high, but is not above the average, considering duty demanded.

No. 25 is, in regard to ropes, a bad case—a small driving sheave, with ill-proportioned V-grooves, constantly slipping when starting, causes heavy wear and tear on ropes and slow operating. Rope costs generally for all types are most difficult to estimate, one set of ropes on the same machine often lasting double the time of an apparently identical set under exactly the same conditions. No hard and fast rules can be laid down, and all that can be definitely stated is that leading lift firms selling both equipments are agreed that, under average equivalent conditions, electric generally do not exceed hydraulic working costs for ropes.

High-pressure direct ram hydraulic lifts with balance cylinders are, for anything but short travels, higher in first cost than any electric equipments. Their only advantage over the latter is a slightly increased factor of safety, against which may be set the fact that they are more costly in lubrication than any other type. Lift No. 1 actually averaged £5 per annum for such purpose alone, or cost of enough energy to run the same duty, somewhat slower electrically, for more than three months. Electric example No. 21, which replaced No. 1 over nine months ago, has, for exactly similar duty and in same attendant's hands, only cost ten shillings for machine oil and three shillings for a change of castor oil in its worm box. Such details may seem insignificant, but the matter is of importance in busy lifts. Repairs must be considered in connection with "wages chargeable to lift" in total cost tables at the end of the paper, and in fact at all times, because a skilled attendant will execute trifling repairs when necessary. This is well shown by example No. 3 and its converted No. 23, where a portion only of a practical man's time is chargeable in working and attending the lift, with consequent minimum repair charges in both equipments. Periodical inspection costs have been included in the tables with repairs, because such expenditure undoubtedly allows adoption of a "stitch-in-time" policy, saving annual outlay on repairs.

Example No. 22 is saddled with rather a heavy full maintenance contract, but is a very busy lift, doing nearly twice the work of any other included.

No. 26 is an example of the usual rather slow-speed, fully automatic, electric press-button lift, and has been at work for nearly a year in quite a public situation. It was manufactured and erected by one of the best known makers, and embodies their latest patents. Its electrical action is as follows: A switch under the cage floor rises and falls imperceptibly on springs when empty, or with the weight of a passenger, respectively. By this arrangement the act of stepping into the cage breaks contact to all landing buttons. After stepping out the

floor springs up again, and remakes the landing push-button common feed circuit. Spring gates are provided and the usual mechanical and electrical locks, the latter in series with feed circuits. Opening of any gate breaks circuit both to the cage and landing push-button feeds.

An ingenious patent three-contact relay is provided for each floor. Pressing a button momentarily for a certain floor energises the solenoid of its particular relay—with which it is in series—through the centre contact. This relay at once rises, first makes a holding-on circuit on the top contact, to maintain its own energy, and almost simultaneously breaks the circuit of its push-button on the relay side at centre contact. The other side of the push-button is fed by a common lead, connected in series through all the relay bottom contacts. Thus any relay in use or sticking up disconnects both sides of its corresponding, and one side of all other, push-buttons, preventing complications. A floor-finding device is connected in series on the end of the floor relay winding, opposite the push-button end. The floor-finding device sets the direction in which the lift has to travel by means of revolving make-and-break arm switches, drum-driven direct from cage by wire cord. According to whether the cage is above or below the floor on which the button is pressed, the floor-finding device will be in up or down position.

There is also a safety switch, which ensures the starting rheostat being in off position before either side of controller or starting solenoid will rise. Thus the whole system is well interlocked.

No. 28 example is typical of the moderate-speed, fully automatic electric press-button lift of the other system best known in this country. It has been working for nearly three years in a semi-public position, with very low maintenance cost, even for the small duty demanded. Its electrical action is as follows: The landing doors, with the usual mechanical and electrical locks, being closed, a momentary pressure of any button, either on the landing or in the car, actuates a corresponding relay in the motor-room, completing an operating circuit through a floor-finding device and the magnet of a reversing switch. The closing of this switch completes the circuit of the motor, gradually starting the armature in the direction required, according to the position of the floor-finding device corresponding with the locality of the cage. This floor-finding device is in the form of a drum, carrying long-rubbing contacts and revolving with the winding gear, from which it is chain-driven. The operating circuit is thereby maintained until the brush or contact on the floor-finding device reaches an insulated point on its path, at which moment the circuit is broken, the reversing switch released, and the motor stopped. Previous to reaching the landing, however, the device, by a short extra contact arrangement, passes current through an additional magnetic switch. This switch closes, causes the field winding of the motor to be strengthened, and thereby slows up the motor. This system results in the cage arriving at landings at a graduated slow, instead of at a fast, speed, rendering the automatic stopping more gentle and ensuring accuracy of level. In connection with the relays is a special compound-wound breaking

magnet, through which the common feed circuit to the various push-buttons passes. Normally, this circuit is closed so that any button may be operated; the moment, however, that any relay closes, this magnet opens its contact, thereby cutting off the supply to all other buttons. When operating from the cage a further special magnet is called into action, which, by closing a contact, effectually cuts off supply to all the

TABLE VII.

TOTAL ANNUAL COSTS (HYDRAULIC EXAMPLES).

Actual Example. No.	9 per Cent. Capital Charges on Prime Cost.	Wages Chargeable to Lift.	Energy.	Maintenance.	Total.
	£	£	£	£	£
1	45·0	39·0	82·1	12·0	178·1
2	41·4	50·0	61·1	16·7	169·2
3	24·3	26·0	46·6	5·0	101·9
4	23·4	52·0	35·7	18·0	129·1
5	45·0	65·0	54·7	10·0	174·7
6	16·2	52·0	44·8	12·2	125·2
7	22·5	70·0	27·5	12·5	132·5
8	45·0	26·0	25·7	9·0	105·7
9	28·8	8·7	33·9	5·0	76·4
10	22·5	72·8	15·5	5·0	115·8
11	18·0	78·0	55·4	9·5	160·9
12	13·5	39·0	26·0	7·5	86·0
Average		£48·2	£42·4	£10·2	£129·6

Overall Average Total Costs = £2·23 per 100,000 Ft.-Cwts.

landing buttons, and is only released upon the opening of a gate or door. This prevents the lift—after it has been operated from the cage—from being called away again upon reaching its destination and whilst the passenger is still in the cage, even though the latter is stationary. By this means the operation of the cage from the landings is prevented until the passenger has left the cage and closed the gate behind him. Whenever the reversing switch closes in one direction, it automatically breaks circuit of the magnet which controls its move-

ment in the opposite direction. This provision is arranged against the remote contingency of two buttons being simultaneously pressed to operate in opposite directions. Should such a thing occur, the movement of the reversing switch in either one direction will immediately break the circuit of the other relay and throw it out of action. This avoids a sudden reversal, which would otherwise be possible if the two

TABLE VIII.

(TOTAL ANNUAL COSTS (ELECTRIC EXAMPLES).

Actual Example No.	10 per Cent. Capital Charges on Prime Cost.	Wages Chargeable to Lift.	Energy.	Maintenance.	Total.
	£	£	£	£	£
21	35·0	39·0	18·2	6·5	98·7
22	37·5	39·0	31·2	37·0	144·7
23	35·0	26·0	14·7	4·0	79·7
24	37·5	52·0	14·8	10·2	114·5
25	40·0	30·0	8·9	10·3	89·2
26	38·0	Nil	6·5	10·0	54·5
27	30·0	70·0	8·6	8·0	116·6
28	45·0	Nil	0·5	2·0	47·5
29	30·0	13·0	0·8	2·0	45·8
30	22·0	39·0	1·7	3·5	66·2
31	16·0	78·0	13·5	2·2	109·7
32	25·0	26·0	6·9	12·4	70·3
Average		£41·2	£10·5	£9·0	£86·4

Overall Average Total Costs = £1·04 per 100,000 Ft.-Cwts.

circuits remained closed. The starting resistance of the motor is controlled by a magnet coming into operation as the motor accelerates, and electrically cutting out the starting resistance in a few steps. This magnet acts entirely automatically, and is not dependent upon any control from the passenger, or upon any mechanical time factor, as in the usual dashpot sliding contact arrangement. The accelerating magnets are fitted with braking contacts placed in the controlling

circuit, so that the operation of the accelerating magnets disconnects the operating circuit of the push-buttons, thereby making it impossible for the motor to be started until all resistance is in circuit. In this manner after the cage, being called, has reached its required landing, should a passenger at that moment press a button on another landing, the motor will not reverse or re-start until the starting resistance is re-inserted.

The final tables include total capital charges of 9 per cent. on hydraulic and 10 per cent. on electric, full prime costs respectively. These allowances include 4 per cent. interest in all cases, and 5 per cent. general depreciation on all hydraulic types. The depreciation on electric lifts and hoists has been worked out from the following point of view. Whatever type is considered, approximately two-thirds of its value represents ordinary fixtures or durable materials, for which 5 per cent. depreciation on prime cost, as allowed for hydraulic, is a fair allowance. The remaining third of first cost represents moving parts, subject to heavier depreciation—probably 8 per cent. included on this portion is ample. This allows a life of about twelve years to breaking-up value. There are a number of electric lifts in the country still working with satisfaction after ten years' use of original working and other parts. One of the electric examples is nine years old, and still quite sound. Thus 5 per cent. on two-thirds, plus 8 per cent. on one-third, first cost, works out at 6 per cent. over all on full prime cost as a fair depreciation on electric lifts and hoists. With maintenance charges, including provisions for new ropes also scheduled separately, it is, however, doubtful whether so high an allowance as 8 per cent. depreciation is really necessary on electric lift working parts.

Wages chargeable to a lift or hoist are a very variable item, from full time of a skilled workman to a few hours per day of a youth. With press-button examples omitted, it will be noted that hydraulic wages average £48·1 per annum, electric £41·2. The majority of these are not skilled attendants, so that unless their services are utilised or desirable otherwise than in connection with these machines, press-button equipments would effect substantial economy in total costs per annum.

The first and last tables, Nos. 1 and 2, 7 and 8, are the essential ones on which comparisons should be based between hydraulic and electric equipments, and from these it will be seen that the actual duty as required, in all examples taken, averages £2·23 with hydraulic and £1·04 annually with electric equipments per 100,000 ft.-cwts. of useful work actually demanded. This is equivalent to a total saving of well over £1 per week, on the usual average lift, by adoption of electric working.

The author herewith expresses his sincere thanks to several prominent lift users who, in addition to his own firm's clients, have placed all particulars and free use of their machines at his disposal for anonymous use. Also to two or three of the leading lift firms for their services in supplying prices, etc., and discussing various hydraulic and electric details in recent correspondence for purposes of this paper.

DISCUSSION.

Mr. S. L. PEARCE: I am under the impression that this is the first paper that has been given showing the relative merits of hydraulic and electric lifts, and I think that the author has made out a very good case for electric lifts on several points. Some time ago I saw figures regarding the maintenance of about 400 lifts connected to the London Hydraulic Power Company's mains, the average cost of which came out at about £5 per lift per annum. The author gives the average cost of 100 gallons of high-pressure water at 6·2d., but in Manchester the price received for power water supplied to lifts is less than half that figure per 100 gallons. Also in the majority of cases 1⅞d. per unit is given as the price for electric lifts. Many lifts work, however, at less than that figure, where current for power is used for other purposes than for lifts. Mr. Pearce.

Mr. A. J. MOORHOUSE: I think it is unfair to the suspended high-pressure hydraulic lift to average the cost with the direct-acting and low-pressure type of lifts along with it. The author should have taken them separately. The cost of hydraulic lifts, during the last seven or eight years, has gone down 100 per cent. The cost of such lifts five years ago was £400, but now they are being put in at about £200. Generally speaking, I consider that the author has compared them very fairly, but I think that the average cost of hydraulic lifts quoted is too high. The average cost of a suspended hydraulic lift is something like £200, and of an electric lift about £326. In my opinion it would have been much better to have left low-pressure lifts out of consideration altogether. Regarding the question of direct-acting hydraulic lifts, I differ very much from the author. There are numerous cases where that class of lift is most suitable, because of the impracticability of fixing overhead gear. They are also useful in buildings that have not been designed for installing lifts. In comparing the cost of the two types of lifts, I think the difference in capital should be taken into consideration, because if the hydraulic lift cost £200, as against £326 for an electric lift, this item would make about £10 difference per annum, representing, say, 10 per cent. on initial outlay. Regarding the difference of 15 to 20 per cent. saved by having the drive fixed on top, it is generally placed below, as a more solid foundation is to be obtained, and there is considerably less hum from the motor and greater accessibility. The saving effected by having the drive fixed on top is nothing compared with the advantages to be obtained by having it below. Mr. Moorhouse.

Mr. BURN: I differ from the previous speaker regarding the question of prices. The price of hydraulic lifts has gone down, but the price of electric lifts has gone down also. I agree with the author that the placing of the motor on top saves both capital and running costs. I know of numerous lifts where the drive is installed on top, and they have been at work for some time, and there is no cause for complaint on account of the hum from the motors. Mr. Burn.

Dr. W. G. RHODES: I consider the figures given in the paper are extraordinary, and I am afraid the difference is almost too good to be Dr. Rhodes.

Dr. Rhodes. true. It doesn't matter to me, however, whether electric or hydraulic types are adopted.

Mr. Crews. Mr. H. C. CREWS (*in reply*): In answering the brief criticisms, it will only really be necessary to emphasise a few points of the paper.

Mr. Pearce says that in Manchester the price of power water for lifts is less than half the 6·2d. per 100 gallons actual average cost of examples included in the paper. Such cheaper rate would of course only apply to a number of machines used by the same large hydraulic consumer in big packing houses, warehouses, etc. Similar conditions would probably favour electricity almost to an equal extent. Large consumers of electricity for power purposes in Manchester or elsewhere would not, in the aggregate, pay anything like the 1·739d. per unit actual average cost of examples in paper. Prices per 100 gallons included represent the actual figures paid by high-pressure users in ten typical cases. Lifts and hoists generally are not large consumers, but as a rule work singly, or under conditions not allowing much economy nor obtaining much advantage from the usual hydraulic sliding-scale rate of charge. Example No. 1, however, obtains water cheaply at the rate of 3·4d. per 100 gallons by working long hours, and also by sharing its supply with another machine doing equal work. When converted to electric working (Example No. 21), and doing equal work under practically similar conditions with comparatively expensive power electricity at $1\frac{7}{8}$d. per unit, the energy bill was reduced to less than one quarter, and this was a good modern hydraulic machine. Two of the prominent London authorities, and also others, now offer electricity at 1d. per unit for all power purposes. Thus, looking ahead somewhat, electric energy costs up to as much as 50 per cent. better than those included in the paper may generally be expected for lift working. It is therefore difficult to see how, in the near future, hydraulic power companies can possibly offer the necessary very substantial reductions in price to compete at all for lift or hoist work.

Mr. Moorhouse will find that all capital costs are duly allowed for in the paper. Prices are actual 1906 ones quoted by leading makers, and are not figures of five years ago. Ordinary hydraulic suspended high-pressure lifts can now be installed for £200, but more expensive equipments are frequently adopted. Only in six towns of the United Kingdom are public high-pressure hydraulic supplies available for these cheaper machines. No attempt has been made merely to compare one particular hydraulic type against electric ones. I have endeavoured to institute comparisons of all costs under the average varying conditions actually existing throughout the country. Hydraulic ram lifts have undoubtedly some mechanical advantages in special cases, but their first and lubrication costs put them entirely out of court in a general economical comparison with suspended types. I advocated the latter almost entirely from economical considerations, this being the main object of my paper.

Mr. Burn, I am glad to see, supports me in the few points discussed.

Dr. Rhodes's fears are groundless. A greater difference in favour of electricity could easily be shown by choosing examples with most

advantageous conditions for *both* equipments. If in all examples taken the 32 ft. average travel condition of the hydraulic as compared with only 28 ft. of the electric machines had been reversed, about another 10 per cent. energy saving would have been credited to the latter. Mr. Crews.

There are, I understand, some 6,000 machines in London alone connected to the London Hydraulic Power Company's mains. Assuming that one-third of these are lifts or hoists, I may point out, as showing the question is of considerable importance, that on the basis of my figures a saving approaching £100,000 per annum could be effected by electric, instead of existing hydraulic, working in that area only.

BIRMINGHAM LOCAL SECTION.

THE TESTING OF TRANSFORMERS AND TRANSFORMER IRON.

By D. K. Morris, Ph.D., and G. A. Lister, Associate Members.

(*Paper read on April* 25, 1906.)

Synopsis.—1. Introduction. 2. Regulation diagram. 3. Diagram of voltage characteristic. 4. The short-circuit test. 5. Proposed standard transformer test. 6. The 3-point wattmeter method. 7. Standard tests for—(*a*) core losses: separation by constant-frequency test; (*b*) copper losses; (*c*) efficiency; (*d*) heating; (*e*) regulation. 8. The auxiliary transformer. 9. Special tests—(*a*) by means of extra turns; (*b*) at half power factor; (*c*) out-of-phase test; (*d*) 3-phase transformers. 10. Hysteresis by slow cyclic change—(*a*) method of constant induced voltage; (*b*) theory; (*c*) application to testing of small samples. 11. Conclusion.

Appendix.—The 3-point method. Temperature by the wattmeter. Improvements in the constant induced voltage method. Separation of hysteresis from eddy-current loss.

1. Introduction.

In the testing of transformers the principal qualities which may have to be investigated are:—

(*a*) Core losses.
(*b*) Copper losses at all loads.
(*c*) Efficiency at light loads as well as full load.
(*d*) Heating at full load.
(*e*) Regulation on all loads and power factors.
(*f*) Insulation (not dealt with in the paper).

The designer and manufacturer of the transformers may also require to know the extent to which the core loss is caused by hysteresis or eddy currents. In addition, it would be useful to determine the excellence of the built-up magnetic circuit, having reference to the permeability of the iron and the low magnetic resistance of the joints.

Excellent methods have been proposed for determining most of the above qualities, but it will be found that they involve the use of different and unusual sources of supply, and also of a considerable number and variety of electrical connections and instruments. Thus to separate the core losses a supply is required whose frequency can be varied, while direct current at low voltage is usually employed when

finding the copper drop or deriving the temperature rise from the increased resistance of the windings.

In order more quickly and conveniently to carry out these measurements, the authors propose a standard test involving but one set of connections, three instruments, and the normal supply. This method necessitates the use of two similar transformers, and is a modification of that first described in 1892 by Ayrton and Sumpner.* It is an application of the Kapp-Hopkinson or differential method of testing direct-current machines.

Before dealing with the standard test in detail, it will be convenient to describe a diagram which we have found very useful and indeed almost indispensable when dealing with any but the simplest transformer problems. This may readily be constructed for any transformer, and shows at a glance its behaviour as regards regulation on loads of any magnitude and power factor.

The Characteristic Triangle.—When the primary winding of a transformer is excited from a constant-pressure supply the secondary voltage varies with the load by an amount depending upon the copper drop in the two windings and upon the leakage flux. The phases of the copper voltages are, of course, those of the currents in the respective windings, but these currents are not quite identical in phase, for they must be just so far out of phase with each other as will enable them together to provide that small out-of-phase magnetising force which will excite the core. This phase difference is very little indeed in all but the smallest transformers. The leakage flux is dependent upon the extent to which the ampere turns of the primary oppose those of the secondary; and as the reluctance of the leakage paths occurs almost solely when they lie in air, the actual leakage flux is proportional to and in phase with the resultant opposition of magnetising forces, while the leakage voltage is in quadrature with it, and therefore, also, with the equivalent total copper drop. The resultant of these two voltages (the combined copper drop and the leakage voltage) is that which must be impressed on one of the windings in order that a current may flow when there is no external resistance in the secondary circuit. It is the "short-circuit" voltage, each component of which, and consequently the whole, is proportional to the current. By determining any two of these voltages, and calculating the third, a right-angled triangle can be constructed, whose sides represent the magnitude and phase of the respective voltages. We have called this triangle the *characteristic triangle* of the transformer.

2. Transformer Regulation Diagram.

In Fig. 1, A C represents the combined resultant copper drop, B C the voltage due to the leakage flux, and A B the resultant voltage. In the case of a unity power-factor load—one in which the secondary current is in phase with the secondary terminal volts—the drop is that due to copper resistance only, the effect of the leakage being to cause a phase difference between the primary and secondary volts without

* *Electrician*, vol. 29, 1892, p. 615.

actual reduction of the secondary terminal volts. If the secondary current lag, so that the power factor is equal, say, to 0·9, then the triangle will take up the position A B′ C′, in which A C′ is again the

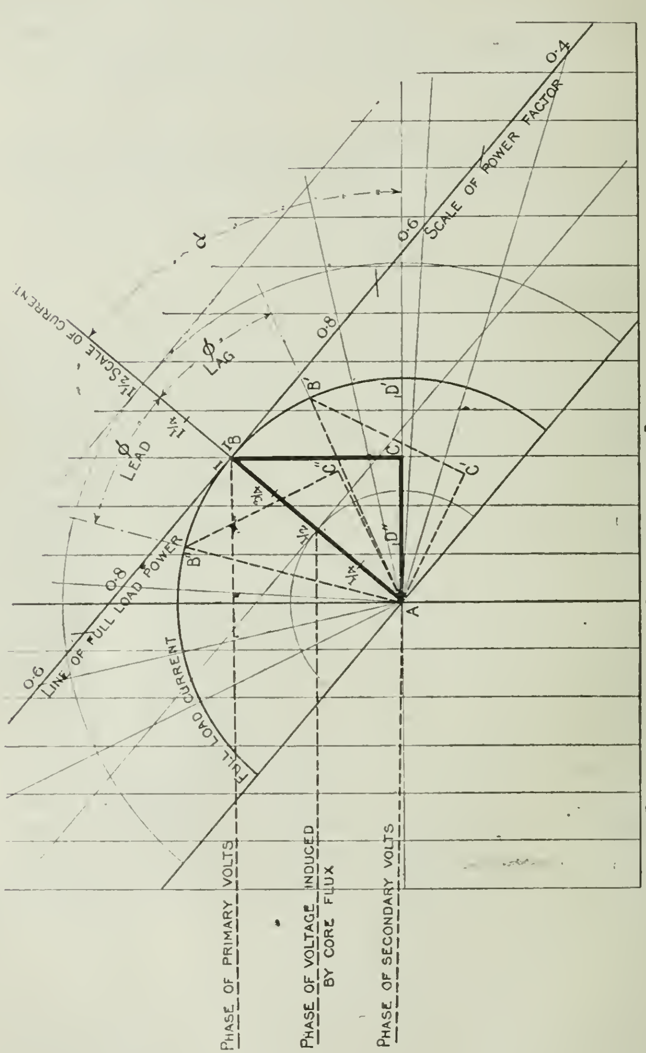


FIG. 1.—Transformer Regulation Diagram.

copper drop, but lagging in phase with respect to the secondary volts. and B′ C′ the leakage volts. It will be seen that the latter now has a component in phase with the secondary voltage and tending to reduce it, the actual drop at the secondary terminals being given

by A D′. Similarly in the case of a leading current of, say, 0·9 p.f., the drop is given by A D″. This drop is considerably less than in the case of a lagging current, since the component of leakage in phase with the secondary voltage is a magnetising component, and tends to boost up the secondary volts.

It is convenient to draw the triangle so that the scale of A C represents the copper drop for full-load current. A scale of current is then marked on A B. Current circles and load lines are now drawn; and also lines radiating from A to represent the various positions of the line A B for different power factors. The drop in secondary voltage which will be caused by any current or load having any power factor, lag or lead, is then immediately obtained from the figure by inspection.

Theoretically it is not correct to project the point B on to the base line, for the primary and secondary volts are not quite in phase. But in commercial transformers with moderate leakage the error is quite negligible. The correction, if it should be required, may be taken as equal to $\frac{(B' D')^2}{2 \times \text{py. volts}}$, which is to be added to the drop of secondary volts, unless the secondary current be leading sufficiently to cause a rise of voltage, in which case it is to be subtracted from the secondary rise.

It has been assumed in the above description that the ratio of transformation is 1 : 1. The diagram is constructed for transformers of any ratio, by expressing the primary voltages and current in terms of the secondary.

The drop due to the no-load or magnetising current is so small in modern transformers that it has been omitted in the transformer diagram.

The characteristic triangle should be drawn to correspond to full-load conditions, and the temperature to which its copper voltage corresponds should be specified. The angle α becomes less as the temperature rises, and the diagram can readily be corrected for any such rise.

Variation in frequency affects the leakage voltage proportionally, without affecting the copper drop. Apart from temperature and frequency, however, the characteristic triangle does not alter in shape, but is simply proportional in magnitude to the current.

3. Diagram of Voltage Characteristic.

A useful modification of this diagram is one in which the voltage characteristic is constructed, and from which, as in the first diagram, the regulation on all loads and power factor may be read direct (see Fig. 2). Construct the full-load characteristic triangle as shown. With centre A and radius A B describe a semicircle. Draw a line from A parallel to C B, and scale so that A G is equal to the full-load current. Mark on A B a scale of cos ϕ, so that A B is equal to unity. Draw a line at right angles to A B, from the point corresponding to the required power factor cutting the

circle in E. Draw E F parallel to A G. Then the line A F is the regulation curve or voltage characteristic for that power factor, the secondary drop being read on the vertical scale. This diagram indicates a simple expression for the copper drop at any load or power factor. Let V_1, V_2, and V_3 represent the short-circuit, leakage, and copper voltages respectively for a given current. Then the secondary drop is given by—

$$V_1 \sin(\phi + \beta)$$
$$= V_1 \left(\frac{V_3}{V_1} \cdot pf. + \frac{V_2}{V_1} \sqrt{1 - (pf.)^2} \right)$$
$$= V_3 \, pf. + V_2 \sqrt{1 - (pf.)^2}$$

These two diagrams, which are modifications of the Kapp circle

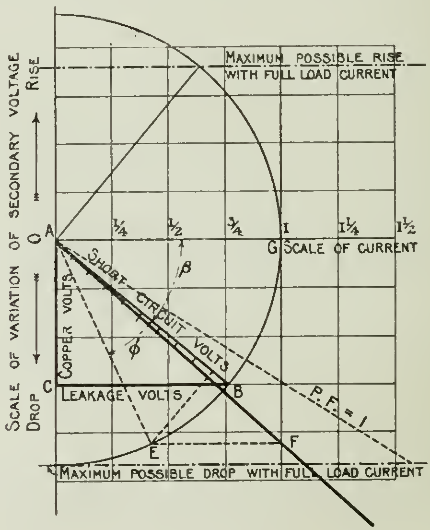


FIG. 2.—Transformer Regulation Diagram.

diagram, have been used by the authors since 1904. It is believed that they are simpler, and in a form more convenient to employ than any previously proposed.*

4. THE SHORT-CIRCUIT TEST.

The characteristic triangle of transformers is usually obtained by means of the short-circuit test due to Professor Kapp. The

* Since writing the above, the authors have found a diagram similar in some ways to Fig. 1 by Bragstad, *Elektrotechnische Zeitschrift*, vol. 22, 1901, p. 821.

secondary of the transformer is short-circuited, and a low voltage applied to the primary of sufficient amount to cause the full-load current to flow in the windings. The instruments required are an ammeter in the primary circuit, and a low-reading voltmeter. The addition of a wattmeter in the primary circuit obviates the necessity of a direct-current measurement for determining the copper voltage, since the wattmeter reading divided by the current gives this quantity directly. Also the wattmeter reading divided by the product of the volts and amperes gives the power factor, and consequently the phase angle between the current and the impressed volts. It is important that the secondary winding be

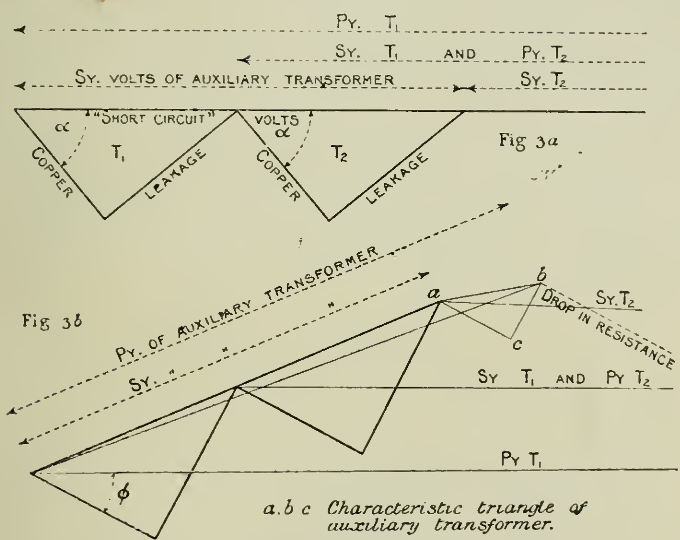


FIG. 3.—Voltage Diagram for Differential Test.

heavily short-circuited, and that no instruments or switches be included in this circuit, otherwise it will be extremely difficult to obtain even an approximately correct value of the characteristic triangle, since the necessary allowances are not easily made.

If two similar transformers are used, the primary and secondary windings being connected in series respectively, and the low voltage inserted in the primary circuit as before, then the test becomes a short-circuit test on two transformers. The voltage required will, of course, be double that for one transformer.

The full working voltage may now be applied to the primary winding of one transformer, without in any way disturbing the circulating current, either in amount or in phase relation to the impressed short-circuit volts. If the connection to the supply is made through a wattmeter, this instrument will give the iron loss in the two transformers. These are in fact

the Sumpner connections for testing transformers on load, the low voltage inserted in the primary winding being that of the auxiliary testing transformer, and the wattmeter in this circuit being connected so as to measure the copper watt loss. If the auxiliary transformer is of suitable ratio, its primary winding is connected to the same supply points as the transformer under test, its low secondary voltage being, therefore, practically in phase with that applied to the two transformers.

The connection between the short-circuit test and the Sumpner test is important, as showing that in each case the current has the same low power factor, a fact which does not appear to be generally known. The phase relations of the various voltages are shown in Fig. 3*a*. The angle α is the angle of lag of the current, which in many transformers amounts to as much as 50 to 60 degrees. It is important also to note that transformer T_1, whose primary voltage is raised, receives the energy and transfers it to its secondary; but that in the other transformer, T_2, the nominal secondary acts as a primary winding.

If the primary of the auxiliary testing transformer be connected to the supply through a regulating resistance, then this resistance will cause a voltage drop in phase with the current, which will twist the phase of the primary of the auxiliary transformer, tending to bring the current more into phase with the supply voltage. The conditions obtaining are shown in Fig. 3*b*.

5. Proposed Standard Transformer Test.

The objections to the Sumpner connections are :—

(*a*) Although the flux density in one transformer is normal, that of the other is either considerably above or below its proper value.

(*b*) The phase angle between the current and voltage depends upon the characteristic triangle of the transformers used, and upon the manner in which the auxiliary transformer is connected to the supply.

In view of the above, the authors propose the standard transformer test described below. The connections and method of carrying out the test are given in relation to a 3-phase supply, but it can be equally well applied to a 2-phase supply. It enables the phase angle of the current with respect to the voltage to be adjusted to any desired amount, and to be kept under control. When single-phase only is available such adjustment of phase angle is impracticable. In either case the necessity of a special short-circuit test is dispensed with.

The connections are shown in Fig. 4. One of the supply points is joined through the wattmeter W_1 to the *middle point* of the secondary winding of the auxiliary transformer. This ensures a complete symmetry in the system. The terminal pressure of one transformer

is raised, and the other lowered, the average flux density of the two transformers thus remaining normal. This allows the variation of iron loss due to heating to be accurately observed during a time test. The voltage of the supply terminals, 2.3, is the mean voltage of the system, and may consequently be used in determining the circulating power.

The primary winding of the auxiliary transformer is connected to the supply as shown through a main current regulator. This admits of the phase of the current being adjusted to any desired amount. By

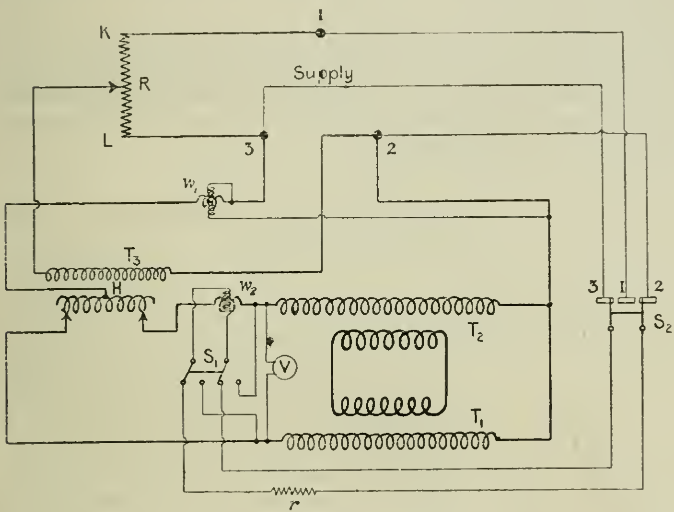


FIG. 4.—Differential Transformer Test.

T_1 T_2 Two similar transformers under test.
T_3 Auxiliary testing transformer.
w_1 Wattmeter reading iron losses of transformers T_1 and T_2.
w_2 Wattmeter reading copper losses of transformers T_1 and T_2, also used to determine current and phase angle by 3-point wattmeter method.
V Low reading voltmeter for measuring secondary voltage of auxiliary transformer.
R Main current regulator for varying phase angle of current.
r Resistance for volt circuit of wattmeter w_2.
S_1 Two-way double-pole volt switch.
S_2 Three-phase volt switch.

moving the adjustable contact of the regulator from K to L, the phase of the impressed short-circuit voltage can be varied through 60°. If the desired power factor is not obtained in this way, the regulator can be moved to each of the other pairs of terminals in turn, the corresponding alteration being made in the other connection of the primary of the auxiliary transformer.

The essential instruments are the wattmeter W_1, measuring the iron losses, the wattmeter W_2, measuring the copper losses, and a variable range voltmeter for determining the supply pressure and the voltage of the auxiliary transformer. These instruments are sufficient to determine all the information necessary to carry out the standard tests. This mode of testing is well adapted to the testing of high tension transformers. No apparatus whatever is included in the high tension circuit nor is any connection made with this circuit, unless the voltage ratio is required.

For some time past the authors have used a device in connection with these and other alternate current tests which renders an ammeter unnecessary, and which also enables the power factor of the current to be accurately determined. It is applicable where the test is carried out on a 2- or a 3-phase supply, and may conveniently be called the *three-point wattmeter method.**

6. The Three-point Wattmeter Method of Measuring Power Factor and Current.

Referring to Fig. 5, let 1, 2, and 3 be the supply points of a 3-phase delta connected system. Let the voltages be e_1, e_2, and e_3, as shown, and let θ_3 and θ_2 be the phase angles between e_1 and e_2, and between e_1 and e_3, respectively. A wattmeter is connected in the phase 3.2, and a voltmeter is available for accurately measuring the voltages e_1, e_2, and e_3. It is required to determine the phase angle of the current in phase 3.2 with respect to the voltage e_1, the actual current, and the out and in phase components of current. A throw-over switch is arranged so that the volt coil of the wattmeter can be connected in turn to the phases 3.2, 3.1, and 1.2. Let the wattmeter readings be w_1, w'_2, and w'_3 respectively. If the three voltages are not equal, the wattmeter readings should be corrected to the amount which they would have read had all the voltages been equal to e_1. Let these corrected readings be w_1, w_2, and w_3. Fig. 6 shows graphically these readings of the wattmeter when the current lags the voltage e_1 by an angle ϕ, and where the line OM represents to scale the product of the voltage e_1 and the current i.

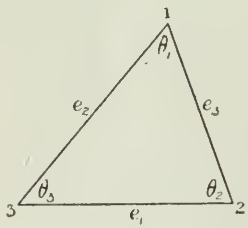


Fig. 5.—Voltage Triangle.

It can be shown that—

$$\tan\phi = \frac{1}{\tan\theta_3} - \frac{w'_2}{w_1\sin\theta_3},$$

$$= \frac{1}{\tan\theta_2} - \frac{w'_3}{w_1\sin\theta_2}$$

* The advantages of this method for measuring power factor have been lately pointed out by J. W. Waghorn. *Electrician*, vol. 56, 1906, pp. 896 and 977.

The in-phase component of current is, of course, $\frac{w'_1}{e_1}$; and having determined the angle ϕ, the out-of-phase component is given by—

$$\frac{w'_1}{e_1} \tan \phi$$

and the total current by—

$$i = \frac{w'_1}{e_1} \cos \phi$$

When all three voltages are equal, and $\theta_1 = \theta_2 = \theta_3 = 60°$, as will usually be the case, the expressions become—

$$\tan \phi = \frac{w'_1 - 2\,w'_2}{\sqrt{3}\,w'_1}$$

$$= \frac{w'_1 - 2\,w'_3}{\sqrt{3}\,w'_1}$$

$$i = \frac{w'_1}{E} \cos \phi$$

$$\text{Out-of-phase component} = \frac{w'_1}{E} \tan \phi$$

$$\text{In-phase component} = \frac{w'_1}{E}$$

The current itself may be determined without reference to the phase angle ϕ.

$$i = \frac{1}{E} \sqrt{w'^2_1 + \frac{(2\,w'_2 - w'_1)^2}{3}}$$

and the out-of-phase component—

$$= \frac{2\,w'_2 - w'_1}{\sqrt{3}\,E}$$

In using this method it is advisable to connect the volt coil of the wattmeter to the supply points in the proper sense, *i.e.*, 3.2, 3.1, and 1.2. If this is attended to, then the sign of the expressions for $\tan \phi$ will indicate whether the current is lagging or leading. Thus, if readings w_1 and w_2 are taken, $\tan \phi$ is positive for a lagging current, and negative if the current leads; if w_1 and w_3 are taken, $\tan \phi$ is negative for a lagging and positive for a leading current. Another simple rule for determining whether the current lead or lag is given by the fact that in the former case w_2 is greater than $\frac{w'_1}{2}$, and in the latter w_2 is negative or less than $\frac{w'_1}{2}$.

It will be noted that two readings only combined with the voltmeter reading are necessary in order to determine the current, its components, and the phase angle.

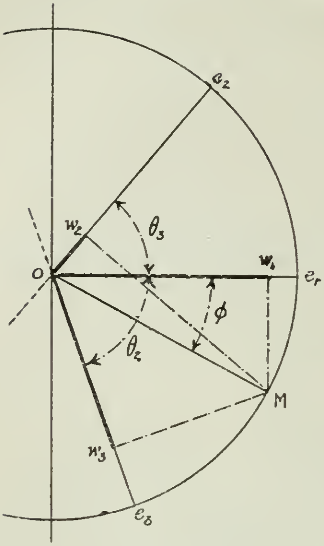


FIG. 6.—Three-Point Wattmeter Method.

Fig. 6 indicates a simple graphical method of determining the required quantities. Set off any two wattmeter readings, such as w_1 and w_2 on two lines, which, if the voltages are unequal, are inclined at the angle θ_3 as obtained from the voltmeter readings, but otherwise at 60°. Draw perpendiculars from the points w_1 and w_2, and the point of intersection M, if joined to the apex of the two lines O, will form one apex of a triangle O M w_1, from which the currents and phase angle may be determined. O M represents the volt amperes.

The authors have found this method the best available for measuring the power factor. It is extremely accurate, and by means of a special volt switch the measurements can be very quickly made. It also has the great advantage of doing away with the ammeter.

7. Detailed Description of Tests.

The following detailed descriptions show how the various qualities of a transformer enumerated on p. 264 may be determined with the instruments and connections shown in Fig. 4 :—

(*a*) *Core Losses.*—The iron losses of the two transformers are read directly on the wattmeter W_1. This wattmeter only carries the magnetising current of the two transformers T_1 and T_2, which is supplied to the system through the primary of T_1; the latter transformer being that on which the impressed voltage is raised by means of the testing transformer. The copper watts of the whole system and the iron watts of T_3 are supplied to the primary of T_3, and consequently do not in any way affect the reading of W_1.

It has already been pointed out that owing to the fact that the average flux density of the two transformers remains constant, the variation of the iron loss with heating can be accurately determined.

To show how perfectly the use of these connections separates the two wattmeter readings into iron and copper losses, it may be mentioned that (*a*) the voltage may be thrown on or off without altering the copper watts at all (the current having remained constant), and (*b*) the current may be switched off without causing the slightest alteration of

the reading of the wattmeter which records iron losses, for the iron loss caused by the leakage lines is imperceptible.

Separation of Core Losses.—In most cases it is sufficient to note the iron watts at the normal voltage and frequency. When it is desired to separate the losses between hysteresis and eddy currents, the test may be done in two ways.

1. *Variable Frequency Test.*—The usual method of taking a set of readings with varying voltage and frequency but constant flux. This is done by keeping the ratio of volts to frequency constant after the manner of the Kapp-Housman test on direct-current generators. The quotient, watts ÷ frequency, is then plotted against the frequency and the losses readily separated.

It is important to take the frequency as low as possible in order to be able to project back to the point which will give the static hysteresis loss. (See Appendix, in which errors of this method are discussed.)

2. *Constant Frequency Test.*—The method here given for separating the losses is not intended to take the place of the variable frequency test as the standard method of arriving at the eddy-current loss, but it is sometimes inconvenient or impossible to arrange for a variation of the frequency of the supply; and in such cases the following test is recommended by the authors as one which will give rapidly a good approximate value of the relative amount of hysteresis and eddy-current loss.

Method of Total Index.—The test consists in varying the voltage while the frequency remains constant. This may readily be done over a wide range if required, especially if a potentiometric adjustment be provided for one supply lead. The iron loss measured by the wattmeter may be expressed—

$$w = a\ \mathrm{E}^x + b\ \mathrm{E}^2$$

where the first term represents hysteresis loss and the second the eddy loss; while by x is meant the Steinmetz index, commonly quoted as 1·6. The total loss, however, may not inaccurately be given as—

$$w = c\ \mathrm{E}^y$$

where y and c are readily determined from two readings by the use of logarithms. Combining the above, we find that $c = a\ \mathrm{E}^{x-y} + b\ \mathrm{E}^{2-y}$, that is, $a\ \mathrm{E}^{x-y}$ must decrease as fast as $b\ \mathrm{E}^{2-y}$ increases. On the assumption that x is constant,* therefore, it will be found that—

$$\frac{w_h}{w_e} = \frac{2-y}{y-x},$$

a simple expression which gives the relation between the hysteresis and the eddy-current core losses, provided that the value of the index, x, for the iron used is known.

* It will be seen that y is so chosen by the rule given below that it is not varying *at* the value of E about which observations are chosen, although it has to be re-determined and must have a different value for another value of E.

All the more recent determinations of x in the range covering transformer working flux densities have given the value 1·5 and not 1·6 for this index, and we have also arrived at figures approximating to 1·50 for transformer cores working at flux densities ranging, say, from 2,000 to 6,000 lines per sq. cm. In tests carried out on two Westinghouse 7½-kw. transformers the authors find that if x be taken as 1·50, precisely the same value is obtained for the ratio of the two core losses by the constant frequency method as by that of constant flux density or variable frequency.

To separate the losses, then, it is merely necessary to take two good wattmeter readings, w_1 and w_2 at voltages E_1 and E_2, near the required value, say 10 per cent. above and 20 per cent. below, and find the value of y as follows:—

$$y = \frac{\log w_1/w_2}{\log E_1/E_2}.$$

Then, taking 1·5 as the value of x, the ratio

$$\frac{\text{hysteresis loss}}{\text{eddy loss}} = \frac{2 - y}{y - 1·50}$$

gives the required information.

Second Method.—Another method, also involving a knowledge of the index x, may be given for separating the losses if two such readings of the wattmeter are known. Let each be divided by the square of the corresponding voltage. The difference between these two quotients divided by the difference between the values of E^{x-2} gives a, as will be seen from the original expression for w. If, therefore, x can be taken $= 1·5$, then—

$$E^{x-2} = \frac{1}{\sqrt{E}},$$

and

$$a = \frac{w_1/E_1^2 - w_2/E_2^2}{1/\sqrt{E_1} - 1/\sqrt{E_2}},$$

from which the value of each loss can be obtained.

(*b*) *Copper Losses.*—The combined copper losses in the primary and secondary windings of the two transformers are given by the reading of the wattmeter W_2. The connections are such that the magnetising current required by the system does not pass through this instrument. The volt leads are commonly shown connected to the terminals of the auxiliary transformer. This often necessitates large corrections for losses in instruments, switches, and leads. There is obviously no necessity for this, since if the volt leads are connected to the actual terminals of the transformers, and there are no instruments or switches in the circuit consisting of the secondary windings, the wattmeter reading gives a true measure of the copper loss in the two transformers under test. Attention should, however, be paid to the effect of the small current taken by the volt coils of the wattmeter or voltmeter. If the main current be determined by the 3-point method, then the

total copper resistance of the transformer—expressed as if all the resistance were concentrated in the primary winding—is obtained. The temperature rise can also be obtained (see below).

(*c*) *Efficiency.*—Since the efficiency of a transformer depends solely on the voltage and frequency of supply, and upon the current in the windings, it is not necessary to adjust the power factor. The product of the voltage e_1 and the current i may be taken as the mean circulating power, the current being conveniently measured by the 3-point wattmeter method. The losses having been determined by the wattmeter readings, the efficiency of one transformer is given by—

$$\eta = \sqrt{\frac{\text{circulating power}}{\text{circulating power} + \text{losses}}} = \sqrt{\frac{w}{w + w_1}} = 1 - \frac{w_2}{2\,w} \text{ nearly.}$$

It is, however, preferable to adjust the power factor to unity, and connect the volt coils of the wattmeter to the supply points 2.3. The instrument then reads the mean power directly, and the determination of the efficiency is thus simplified.

(*d*) *Heating.*—When testing a transformer it is important to determine the final temperature which will be reached as the result of a continued application of the rated full load. An approximate idea of this temperature may be obtained by observing during the test the readings of thermometers, placed in suitable positions in the transformer. When these indicate that final conditions have been reached, it is usual to determine the mean resistance of the windings by a direct-current voltage-drop measurement, from which the temperature rise can be calculated. This changing over to another supply, even if the latter be readily available, takes time, and is always inconvenient. There is, moreover, no necessity for it, as the resistance can be determined quite easily from the wattmeter and voltmeter readings by the 3-point method already described. The authors have found this quite the most satisfactory way of determining the temperature rise by resistance measurement. If it has not previously been pointed out, it is because no sufficiently accurate determination of copper drop by the alternating-current instruments could formerly be obtained. Accuracy is necessary, for the whole temperature rise is represented by a 20 per cent. increase at the most in the resistance drop.

In conducting heating tests a great saving of time is effected by working the transformers at a considerable overload, which is kept on till they have reached the estimated final temperature under normal conditions. The load is then reduced to its proper value, and a short period will suffice to show how nearly the normal temperature rise for full load has been attained. When this has been approximately reached, the normal full-load current should be maintained and the temperature carefully watched for constancy during half an hour. The final value can thus be correctly gauged.

It may be urged against this test that, although the final temperature is obtained, the time required to reach this temperature within any given small percentage is not stated. From the initial rate of temperature

rise, however, with any given overload this may be obtained. For this purpose it is convenient to employ an overload such that the total loss is just doubled, which would usually be about a 60 per cent. overload. If the initial rate of rise be noted and the time, T, necessary to give the probable temperature rise at this rate calculated, then the time during which the overload should be kept on is about 1·5 T., while the time which the transformer would have taken when working at normal load to arrive within 1 per cent. of this probable temperature is 9·3 T. These estimates assume that the rate of generation of heat throughout the transformer is uniform.*

(*e*) *Regulation on all Power Factors.*—It will usually be sufficient to determine the characteristic triangle of the transformers, and to draw the diagram giving the required regulation curves in the manner previously described. The triangle is best determined by first adjusting the current to its full-load value, and the power factor to unity, and then observing the low voltage impressed on the primary circuit, and the reading of the wattmeter, W_2. This latter reading divided by the current will give the copper voltage. The ratio of the copper voltage to the impressed voltage is the cosine of the phase angle of the current with respect to the latter voltage, so that the leakage voltage is given by—

$$\sqrt{(\text{short circuit volts})^2 - (\text{copper volts})^2}.$$

The triangle thus obtained is for two transformers, half the values giving the characteristic triangle. It may be noted that the difference in the voltages of T_1 and T_2 is practically the double copper voltage when the power factor of the circuit is unity, and if the power factor be adjusted till the current is exactly 90° out of phase, as is easily done with the arrangement shown in Fig. 4, then this difference is a direct measure of the leakage volts. On any power factor this difference will, of course, give the regulation of the transformer. It might be argued as an advantage of the above method that the determinations are made under normal conditions as regards flux density, which is, of course, not the case with the short-circuit test. But the authors have found that the results obtained by each test are practically identical, thus showing that the leakage voltage does not vary appreciably with the flux density. In cases where it is not convenient to vary the power factor in the manner described, the characteristic triangle may be determined by a special test described below.

Although leakage does not affect the regulation of a transformer when working on a load of unity power factor, yet it becomes serious even in modern and well-designed transformers when lagging currents have to be supplied by the secondary. There is one method of reducing leakage which has been used in the design of induction motors, but which does not appear to have been brought forward in connection with transformers. This consists in the use of copper damping circuits so placed among the windings as to choke off the

* See the curve by Goldschmidt, *Journ. I.E.E.*, vol. 34, p. 670.

alternating leakage flux. The leakage can probably by this means be largely done away with, although with a slight loss of efficiency. The device might be difficult to apply, especially in high-tension transformers, but cases should arise in which the increased expense would be worth while.

8. The Auxiliary Transformer.

A convenient testing transformer is one of the core type, in which the windings are easily accessible, and which permits of additional secondary turns being wound on as required. The normal transformation ratio should be about 25 : 1, but ratios above and below this value should be easily obtainable. A satisfactory arrangement consists of bringing out the middle point of both the primary and secondary windings, and, in addition, tapping each end of the low-voltage secondary winding at, say, six points, each tap being connected to a point of a multiple-way switch. This divides each end of the winding into five sections, and if these five sections correspond to one-fourth the whole winding, transforming ratios of from $12\frac{1}{2}$ to 50 will be obtained, which will be ample in most cases. The current may be adjusted to definite values by inserting a small adjustable resistance in the primary circuit of the auxiliary transformer. In varying the secondary voltage by means of the multiple-way switches, sections are cut out at each end of the winding, alternately, or preferably at each end simultaneously, in order to keep the mean voltage of the transformers constant. The necessary adjustment for current can, of course, be obtained by using a single ratio transformer (the middle point of the secondary being accessible) in conjunction with an adjustable resistance in the primary circuit. But this arrangement is not so good, since a relatively heavy resistance is needed. It is also difficult to adjust the power factor.

The ideal method of setting the phase of the current in the differential transformer test would be by the use of a worm-and-wheel booster, or induction regulator, whose stator windings are excited from the 3-phase supply terminals. A single circuit of the rotor would be inserted into the primary circuit in place of the secondary of the testing transformer ; and by means of regulators in the stator supply the voltage could be set to that corresponding to any desired current, while the phase of this current could be set as required by simply turning the rotor to the required angle. Should the expense of such a booster be not warranted, an equivalent device would be an induction motor with wound rotor which was locked in the required position.

A system of three regulators, if they were available, could always be arranged so as to furnish the necessary current to the primary of the testing transformer at any desired phase. A water resistance with three fixed and three movable electrodes may also be employed.

9. Special Tests.

(*a*) *Testing by Means of Extra Turns.*—In the case of small transformers, a method of employing the differential test which does not necessitate the use of an auxiliary testing transformer, and is convenient

with some designs, is to wind a few extra turns round the magnetic circuit of each transformer. These turns are connected in series with either the high or low tension windings, as is most convenient. On one transformer they should tend to increase, and on the other act in opposition to the normal voltage, the mean voltage thus remaining constant. The wattmeter W_2 is connected in the same circuit as the extra turns, and if its volt leads be connected so as to include these turns only, the instrument will read copper watts. The wattmeter W_1 will read the sum of the iron watts, the copper watts in the two transformers under test, and the copper watts in the extra turns. The latter may be calculated and allowed for from a knowledge of the current and the resistance of the turns. The power factor in this test has the same low value as in the short-circuit test.

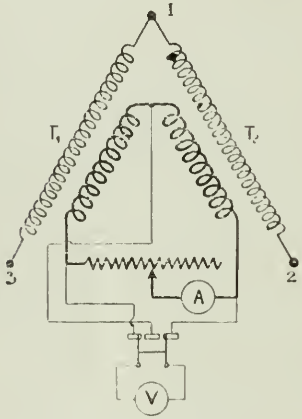


FIG. 7.—Half Power Factor Test.

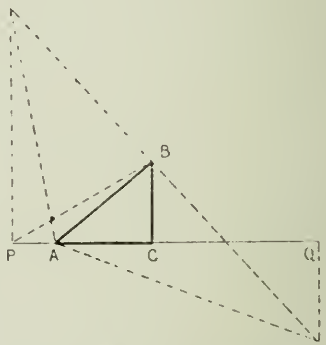


FIG. 8.—Method of Determining Characteristic Triangle.

(*b*) *Half Power Factor Test.*—When through lack of apparatus it is found impossible to vary the phase angle of the current, all the above tests may still be carried out as described, with the exception of that determining the characteristic triangle. This can readily be done, however, when a heavy current is available, by connecting the two transformers to the 3-phase supply in the manner shown in Fig. 7. The free ends of the secondary windings are joined through a non-inductive resistance, such as a main-current regulator or liquid controller, and a current will flow which is in phase with the voltage 2.3, that is, its power factor will be one half. In one transformer this current will lag behind the voltage by 60°, and in the other it will lead by a similar amount. By means of a voltmeter and change-over switch the regulation at these power factors with varying current may be observed. The characteristic triangle itself may be determined by observing the secondary voltage drop or rise in each transformer when carrying full-load current.

Referring to Fig. 8, let A P be double the drop or rise in that transformer which takes a leading current, and A Q double the drop in the transformer taking a lagging current. Let $A\,C = \frac{1}{2}(A\,P + A\,Q)$. Draw the line P B inclined to P Q at 30°, and draw B C perpendicular to P Q. The triangle A B C is then the full-load characteristic triangle of the transformer. It is necessary to double the voltage difference, as otherwise, since the power factor is only 0·5, the triangle would correspond only to half full-load current.

(*c*) *Out-of-Phase Test.*—When double the normal primary voltage is available, the regulation for zero power factor, namely, the leakage

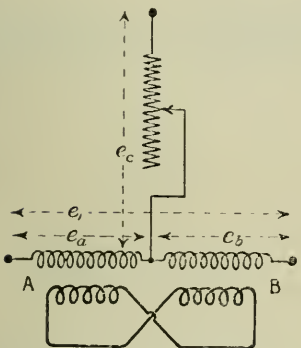


FIG. 9.—Out-of-Phase Test.

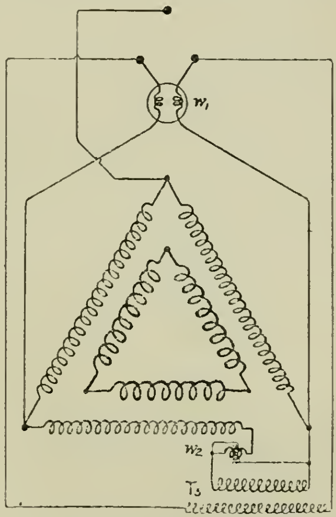


FIG. 10.—Three-Phase Transformer Test.

T_3 Auxiliary testing transformer.
w_1 Wattmeter measuring iron losses of 3-phase transformer.
w_2 Wattmeter measuring copper losses of 3-phase transformer.

drop alone, may be obtained by making the following very simple test (Fig. 9):—The two primary windings are joined in series across the supply, and the two secondaries in opposition. The point of junction of the two primary windings is then connected through a water resistance (or other adjustable rheostat capable of carrying twice full-load primary current) to the third terminal of the 3-phase supply. When this cross current flows, each primary and secondary winding is carrying its normal full-load current, but the currents are *exactly out-of-phase*, with the voltage leading by 90° in the one and lagging by 90° in the other. The leakage drop is one half the difference in the terminal voltage of the transformer primaries which occurs when

the out-of-phase current is switched on, while the copper drop is the corresponding change in the value of the cross-voltage, e_e.

(*d*) *The Testing of Three-phase Transformers.*—Fig. 10 shows the application of the differential test to the 3-phase transformer. The 3-phase wattmeter W_1, or a single-phase wattmeter with throw-over switch, will measure the iron losses. The copper losses are measured by the wattmeter W_2. The voltages across the secondary windings of the three transformers will give the regulation for unit power factor, 60° lead and 60° lag respectively. The characteristic triangle may be determined by the method described in connection with the

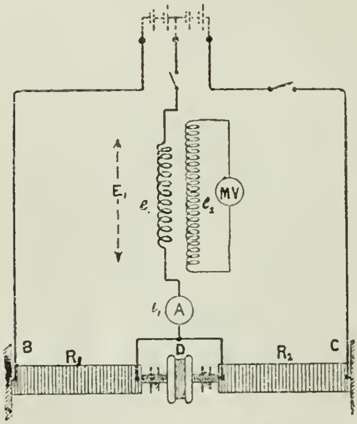


FIG. 11.—Connections for Magnetic Test.

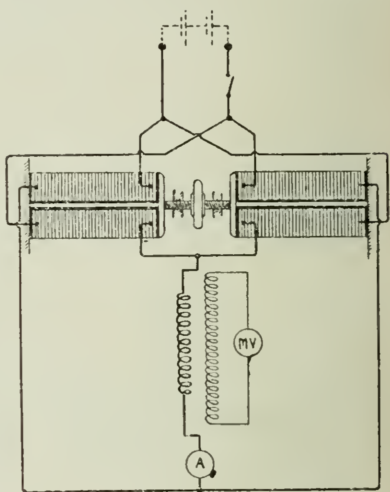


FIG. 12.—Connections for Magnetic Test (each of the four sets of carbon blocks are electrically separate except for the connections shown).

half power-factor test. It may be noted that in this test, as in the differential test on two transformers, no power is taken from the mains, except that required to overcome the losses. Should there be reason to expect a difference in the regulation of the three transformer sections, the testing transformer should be excited successively from each pair of supply leads so that the regulation is obtained for each section for unit power-factor and half power-factor lead and lag.

10. Hysteresis by Slow Cyclic Change.

The two methods already given for arriving at the loss through hysteresis alone in the transformer core are based, the one on the possibility of varying the frequency, and the other upon a knowledge of the index x. To determine the latter and generally to eliminate all the effects of rapid magnetic variation, and arrive at the true hysteresis loss, is important, since, if the dimensions of the core and

the number of turns of the windings are known, the quality of the iron as it exists in the core can be exactly stated. Ballistic methods of measuring hysteresis are not only troublesome, but impracticable, on account of the mass of iron to be magnetised. There is, however, one method available, which was proposed by C. F. Scott and appears to have been first described in a paper by J. S. Peck, cited below.* It is the method of *constant induced voltage.* The primary current supplied from a low voltage direct-current source is varied from a negative to a similar positive value at such a rate as to keep the small secondary induced voltage constant throughout the whole change. This method, which is at once easy to carry out, expeditious, and accurate, does not appear to have attracted the attention it deserves. The present authors have developed this method, and show here how by its means the hysteresis not only of large transformers, but also of small samples of transformer iron, or rings of cast steel, may be tested for permeability and hysteresis.

(*a*) *Method of Constant Induced Voltage.*—To find the hysteresis loss in a transformer core working at a given flux density, the following connections are suitable :—In the first place, a rheostatic device is required which will permit of a *continuous* adjustment of the small magnetising current from the value necessary to give the required flux density right down through the zero value to the negative maximum value. To effect this, a 3-wire, low-voltage source of current is convenient. Two cells or two pairs of cells in series will suffice. Two light carbon rheostats are mounted back to back with their handles bound together so that when the one is tightened the other is loosened (Fig. 11). They are joined in series across the outer supply points, while the central point is led through the transformer winding to the middle supply terminal. When the rheostats are equally tight, then, although they take a current from the outer points, yet no current flows through the transformer. If the rheostat handle is worked so as to tighten R_1 the potential of the junction point D will tend to coincide with that of B, so that a potential difference will be set up across the terminals of the winding ; and the current in it may then be continuously adjusted down through zero to a negative maximum.

A compound carbon rheostat which is suitable for working this test from an ordinary 2-terminal supply is shown in Fig. 12. This requires, however, a special construction. The winding is placed across a kind of Wheatstone bridge.

(*b*) *Theory of Constant Induced Voltage Method of Magnetic Testing.*—Consider the rate of supply of energy of the primary winding. It is

$$E_1 i_1 = e_1 i_1 + i_1^2 r \text{ watts.}$$

The energy-change during any given period is

$$\begin{aligned} \int E_1 i_1 dt &= \int e_1 i_1 dt + \int i_1^2 r_1 dt \\ &= \text{magnetic energy} + \text{ohmic loss.} \end{aligned}$$

* "On Testing Large Transformers," J. S. Peck, *El. World and Engineer*, New York, vol. 37, 1901, p. 1083 ; *Science Abstracts*, vol. 4, 1901, p. 891.

But e_1 is kept constant $= Ke_2$ where $K =$ ratio of transformation in transformer. Hence

$$\text{Magnetic energy} = Ke_2 \int i_1 \, dt$$

Plot i_1 against t for rising and falling currents. The area of the resulting loop in ergs, when multiplied by Ke_2 and divided by the volume of the iron in the core in cubic centimetres, is the hysteresis loss in ergs per cubic centimetre per cycle (Fig. 13).

It is thus merely necessary to note time readings of the ammeter or to use a recording instrument to obtain at once the hysteresis loss.

It is important to fix upon an induced voltage large enough to be read easily on the milli-voltmeter. The rate of flux change which determines this voltage should, however, not be so great that the cyclic

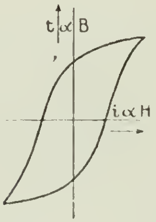


FIG. 13.

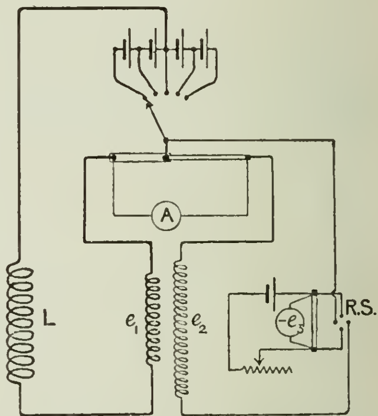


FIG. 14.—Connections for Magnetic Test.

half-process is over in a time too short for the proper noting of the successive readings. Twelve or sixteen readings, six or eight during each half, taken at intervals of not less than, say, five seconds, will suffice to determine the curve. Considerable practice would be necessary in order to keep the induced voltage approximately constant, but it is surprising how little effect is produced on the resulting curve by even large fluctuations in the induced voltage, provided only that an effort is made to keep the *average* value at the required amount.

A set of hysteresis loops between increasing limits of flux density can be obtained in an extremely short time compared with that required for recording the corresponding ballistic tests ; while with the method of constant induced voltage, the instruments used, consisting of an ammeter, a milli-voltmeter, and a watch, can be readily maintained direct reading, so that the observations taken are practically ready for plotting. The working out of a ballistic test is, on the other hand, a long process. The new method when applied to transformer

cores admits of an accuracy which is not second to that attainable by the ballistic method. Thus, by the test, the Steinmetz coefficient, η, and the index x, can be determined in the expression—

$$\text{Loss per cycle} = \eta \,.\, \backsim \,.\, B^x.$$

Although, as above stated, it is not necessary to keep the induced voltage more than approximately constant, it is certainly a drawback to the test that even this is only attained by close attention, and some skill. By means of the following method, however, it is possible to render the process to some extent automatic :—

If the secondary, instead of being connected to the voltmeter be short-circuited through a heavy shunt, then, by passing a suitably large current from an external source through the shunt, the induced E.M.F. may be opposed in the secondary circuit by a voltage equal to that which is being taken as the constant induced voltage value. Thus the condition for the correct rate of flux change will be that of zero current in the secondary. If, however, current does flow, it will, by its ampere turns check the errors which may arise in the magnetising force of the primary. The net ampere turns of the two windings will be right, but the ammeter will no longer read proportional to this effective magnetising force. By means, however, of the connections shown in Fig. 14, it is possible to make the ammeter read the net ampere turns alone and not the current in one circuit or both. If a recording ammeter be used, the measurement of hysteresis is still further simplified. (See Appendix.)

(*c*) *Application of Constant Induced Voltage Method to Small Samples.*— The arrangement shown in Fig. 11 is used, the carbon rheostats employed having plates 3½ ins. square. The primary winding of the transformers is replaced by a *single straight length* of 19/16 cable. The sample consists of a strip, 1 in. or 2 ins. wide, and, say, 4 ft. long, cut from the transformer sheet and rolled up tightly on a wooden former turned to a diameter of, say, 5 cms. A wide groove is left in the former, in which the secondary, consisting of a flat coil designed to suit the indicating instrument, is placed. The sample is passed through this as it is rolled up, and the whole is then slipped on to the straight conductor. The terminals of the secondary are either joined straight on to a sensitive indicating milli-voltmeter, or an opposing E.M.F. is employed as in the transformer test. "Air lines" can be compensated for by the use of a few turns of wire suitably placed near the straight conductor.

Any required number of curves of current as it varies with time are then taken by the method of constant induced voltage ; and, as the dimensions of the magnetic circuit are known, the curves can, if required, be reduced to B—H curves, and all the necessary magnetic data obtained.

The flux-densities occurring in transformers are caused by fields not exceeding 2 to 4 c.g.s. units. The magnetic field along the circumference of a circle of a cms. radius, through whose centre a conductor carrying i amperes is passed, is $0{\cdot}2\ i/a$. If $a = 2{\cdot}5$ cms., then

for $H = 2$ and $H = 4$, $i = 25$ and 50 amperes. In laboratories, where the low voltage supply need not come from portable cells, these currents are readily obtainable.

Thus a sample of iron can be tested in the form of a ring without being wound at all. It has merely to be rolled up on the former. And the method of constant induced voltage is equivalent to a ballistic test, the magnetic circuit of the sample being closed.

Considerable experience with this method of testing samples during the last few months has shown clearly to the authors its great superiority for ordinary magnetic testing. It is not difficult to obtain the permeability and hysteresis curves, and the Steinmetz co-efficient and index for a sample in the course of an hour; a result which cannot be obtained by the ordinary ballistic method.

Since the method involves only a slow magnetic process, samples of cast steel in the form of rings, which cannot be dealt with ballistically, may be tested for magnetic quality.

11. Conclusion.

The principal points referred to in the paper may be thus summarised :—

The behaviour of a transformer when loaded at various power factors is best considered by means of the regulation diagram here given.

The short-circuit test can equally well be carried out with the transformer core excited.

The 3-point wattmeter method is probably the most accurate means of measuring power factor and current when carrying out single-phase tests on transformers or motors from a 3-phase supply.

By bringing the supply to the middle point in the testing transformer when carrying out the differential test, symmetrical conditions are obtained, thus permitting of a normal determination of the various losses.

By varying the voltage only and taking wattmeter readings the core loss of a transformer may be separated into hysteresis and eddy-current loss by the method of the total index.

Wattmeter readings in combination with the 3-point method serve as the best means of measuring the temperature rise in heating tests.

The method of constant induced voltage affords a ready means of finding the true hysteresis loss, and is probably the best way of testing iron samples.

APPENDIX.

In support of the conclusions arrived at in their paper the authors add the following :—

Accuracy of the 3-point Wattmeter Method.—Good wattmeters can now be obtained of excellent construction, which, as instruments of precision, rank with the best of standard direct-current instruments. Accurate voltmeters are also obtainable. It is the advantage of the

3-point method that it extends the use of these instruments to the measuring of current and power factor, and even to the determination of temperature rise. No additional apparatus is required, and the ammeter may be dispensed with. To obtain accurate results, however, it is necessary that there be no inductive lag of the current taken by the volt coil, for, although this will not appreciably influence measurements at high power factors, it may cause serious error when the main current is much out of phase, and even reverse small readings of the wattmeter. Low power-factor readings are unavoidable when using the 3-point method. A careful test was therefore made on a precision wattmeter of Siemens's make when working with full current at approximately zero power factor. By inserting an inductive resistance into the volt circuit of the wattmeter it was proved that the inductive lag in the volt coil was certainly less than half a degree. A severe test of the accuracy of the 3-point method is the following:—

Temperature-rise Test on Transformers by the Wattmeter.—(*a*) The total copper losses are indicated by the wattmeter when connected as shown in the paper.

(*b*) The current is obtained by the 3-point method, no effort being made to regulate it to an exact value.

(*c*) The resistance is obtained by dividing the copper watts by the square of the current. By this method the authors have repeatedly found it possible to measure the resistance to within ½ per cent. accuracy. This accuracy means that ordinary temperature rise can be determined correct to about 1° C. Comparing this with the direct-current method of measuring temperature rise by increase of resistance, it will be seen that, while the wattmeter method is equally accurate, it is much more convenient and does not necessitate any interruption of the test.

The Constant Induced Voltage Method of Magnetic Testing.—The simple test introduced by Scott can be improved as pointed out in the paper, but some skill is required in testing *small* samples in order to keep the induced voltage constant. The following improvements in the method are therefore useful :—

(*a*) *A heavy secondary winding* is short-circuited through two low resistance shunts, one of which, in combination with the main ammeter shunt, permits direct observation of net ampere turns in the manner described in the paper ; and the other permits a small voltage to be inserted in the secondary circuit equal and opposite to that which it is desired to induce in that winding. A milli-voltmeter is connected across the latter shunt, and the regulation is carried out in such a way that the reading maintains the same value throughout the whole process as that to which it was originally set before the secondary circuit was closed (see Fig. 14). When the resistances thus inserted in the secondary are found to be excessive it is better to omit them. The secondary then takes the form of a heavy sheath of copper, or annular copper box, which forms a very perfectly short-circuited secondary around the sample. A third winding of thin wire is then also required, which is interposed in opposition in the leads of the main ammeter shunt.

The number of turns of this third winding is adjusted until the main ammeter records net ampere turns as before.

(*b*) A further improvement consists in the *insertion of a large inductive resistance* or cored choking coil in the magnetising circuit. This we have found to be very effective in improving the steadiness of regulation, and the agreement which is possible between successive hysteresis loops is very perfect, the areas working out alike within 1 per cent.

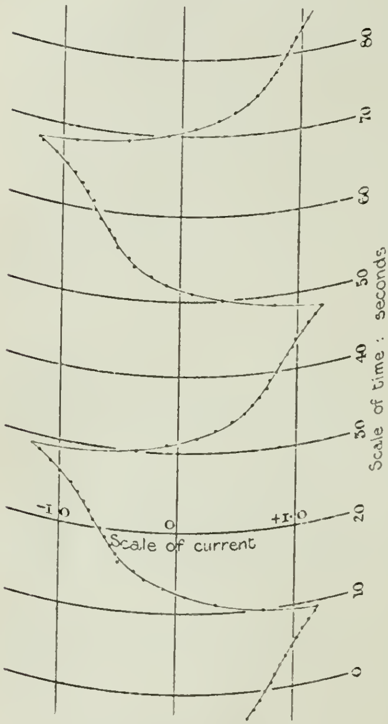


FIG. 15.—Hysteresis Curves of $7\frac{1}{2}$-k.w. Westinghouse Transformer.

Limits $\begin{cases} \pm\ 56{\cdot}3 \text{ ampere turns.} \\ \pm\ 6{,}100 \text{ lines per sq. cm.} \end{cases}$

(Taken with Everett-Edgcumbe Recording Instrument, giving one dot each second.)

(*c*) *A recording instrument* in place of the ammeter saves a large amount of labour. It is important that the pen shall not drag along the paper. If it is of the type in which impulses are given, say, every five seconds, the number of dots gives an exact measure of the induction change (Fig. 15).

(*d*) If it is only desired to measure permeability, it is merely necessary to determine accurately the *total time* for one reversal between observed current limits. The ratio of this time to the total change of current is a measure of permeability.

(*e*) When it is only the hysteresis that is required, the quantity $\int idt$ is best measured by an ordinary *ampere-hour-meter* of the mercury type.

The meter should be carrying its full current at about the top limit of current used in the test. With a slow process such as that used, the meter will reverse exactly as the current passes through zero, and the net turns and decimals of a turn of the brake disc during the passage of current from its positive to negative value is a good measure of the hysteresis, provided, of course, that the current is changed at such a rate that the secondary induced voltage remains constant. By reversing the meter at each limit the total hysteresis of several cycles will be recorded, and therefore also the average hysteresis loss per cycle. When testing either small or large samples the number of revolutions available will be found to be about 10 to 30 per reversal.

(*f*) With transformers having a H.T. winding the hysteresis can be measured on an *integrating wattmeter or watt-hour-meter*, the reversal being carried out at any irregular speed, not necessarily at that giving constant induced voltage. A simple reversing key is all that is required, no rheostatic reversal being needed. Small samples, however, cannot, unfortunately, be tested in this way, without arranging by means of a divided resistance to have a voltage, say, 1,000 or 10,000 times the induced voltage.

We have carefully tested the hysteresis of the $7\frac{1}{2}$-k.w. transformer core referred to in the paper by the method of constant induced voltage, and find that in the region of maximum permeability, the value of the index, x, in the Steinmetz formula is very close to 1·5. We have also derived the value of x from a number of reliable figures for hysteresis which have been published.* The results, although differing widely at high flux densities, agree in showing that the index does not vary more than 2 per cent. from 1·5 in the region of maximum permeability. This statement applies to a range of over 1,000 lines per sq. cm. above and below the actual maximum of permeability. All the observations agree also in giving increased values varying up to 2 for low flux densities.

In a paper in 1904 it was pointed out by Mordey and Hansard † that the eddy-current loss did not vary with the square of the frequency. This conclusion has since been confirmed by Messrs. Gumlich and Rose. ‡ This is due to the fact that the eddy-current paths are not without an inductive resistance corresponding to the skin effect. Such inductive action will vary with the frequency, but should vary hardly at all with the flux density, especially in the region of maximum permeability in which transformers are made to work. Mr. Mordey states in his paper as the result of a large number of tests that, while the eddy-current loss is far from being proportional to the square of the frequency, yet it *is* substantially proportional to the square of the induction density. Thus the constant-frequency method of separating the iron losses may possibly lead to a more accurate result than the method of varying the frequency, and in any case the assumption of a 1·5 index seems to be sound.

May, 1906.

DISCUSSION.

Dr. W. E. SUMPNER: The paper is a most interesting one, and contains a good deal of useful work. It is particularly interesting to me, because, fourteen years ago, I developed the method of testing transformers which corresponds to the Hopkinson test on direct-current machines. When it is required to test machines for a long heat run, Dr. Sumpner.

* J. A. Ewing, *Proceedings Institution of Civil Engineers*, vol. cxxvi. p. 185. H. F. Parshall, *Ibid.*, p. 220. Gumlich and Schmidt, *Elektrotechnische Zeitschrift*, vol. 22, 1901, p. 691. H. Maurach, *Annalen der Physik*, vol. 6, 1901, p. 580; *Science Abstracts*, vol. 5, 1902, p. 39.

† *Electrician*, vol. 53, 1904, p. 790.

‡ *Elektrotechnische Zeitschrift*, vol. 26, 1905, p. 503.

Dr. Sumpner.

the method is very simple, and is a thoroughly good one, on account of the economy in power. It is also particularly suited when any careful investigation has to be made, but the method then becomes elaborate, and requires skill to carry out. But the transformer is really such a simple piece of apparatus, and its losses are so easily determined, that the Hopkinson test is not absolutely necessary. This also I pointed out fourteen years ago, and I showed then that two tests only are required, each of which can easily be made. These are a measurement of the iron losses by means of a wattmeter, and the short-circuit test to determine the copper losses. Usually, the same wattmeter can be used for both tests. I thoroughly appreciate the authors' modification of the method as one which has great advantages where a careful investigation has to be made and it is desirable to make the test thoroughly satisfactory from a theoretical point of view. But in most cases the extra complication is really not necessary or advisable. I much appreciate the method of testing transformer iron described in the paper. This was suggested by Mr. Scott, and applied in the case of large transformers by Mr. Peck. I am surprised to find that it is also applicable to small transformers.

Professor Kapp.

Professor G. KAPP: I appreciate the objection made by Dr. Sumpner to the complication of using a special boosting transformer, especially in practical work, in order to boost up the voltage of one of the transformers under test and lower that of the other. This necessitates a special transformer with the middle point available. The same result can be easily obtained by a method which I have previously used, and in which I have not found any grave errors. The auxiliary testing transformer is connected in circuit, and a throw-over switch arranged so that one lead of the supply to the transformers under test can be connected first to one end of the auxiliary transformer and then to the other. If wattmeter readings of the iron loss in the transformers are taken, it will in one case be the sum of that due to normal flux in one transformer and an increased flux in the other, due to the boosting up of the voltage. In the other case it will be that due to normal flux in one transformer and a decreased flux in the other, due to the boosting down of the voltage. The mean of the two wattmeter readings gives very nearly the loss in the two transformers at normal induction. It is not quite correct, since when boosting up the increase of loss is greater than the decrease when boosting down by an equal amount. The error is, however, inappreciable, and by tolerating it we take away the reproach which may otherwise be made against the method on account of the necessity of a special testing transformer.

Dr. Hay.

Dr. ALFRED HAY (*communicated*): In connection with the calculation of the core loss from the results of tests on small samples, attention may be drawn to the uncertainty which arises from the non-uniformity in the magnetic flux distribution due to the varying length of the lines inside the core. Any departure from uniformity results in an increase of the hysteresis loss, and a still greater relative increase in the eddy-current loss. It is curious to note, in this connection, the effect of a poor joint in the magnetic circuit. A core having butt joints will, for

a given total flux, have its hysteresis and eddy-current loss reduced by an increase in the reluctance of the joints, if we assume that the small air-gaps at the joints are of uniform length. It is therefore quite conceivable that under certain conditions the presence of a certain amount of reluctance at the joints, although increasing the magnetising current, would on the whole be beneficial as tending to reduce the core loss and increase the over-load capacity of the transformer. Dr. Hay.

Mr. J. T. Morris: In reference to the determination of hysteresis by slow cyclic change I am in thorough agreement with the authors—from experiments I have made—that the method of *constant induced voltage* for the determination of hysteresis loops for large quantities of iron without doubt deserves to be brought much more generally into use. My attention was drawn to the method some five years ago, when determining the leakage coefficient of certain dynamos. A suitable liquid rheostat being placed in series with the field coils of the machine, the current is gradually increased from zero to normal value at such a rate that the induced voltage developed in a single "search" turn on the limb of the machine is maintained constant. The duration of the period of growth is carefully noted. A single "search" turn on the armature is similarly treated, the same voltage being generated. Then the ratio of these times gives the "coefficient of leakage." Further, if the voltage generated be known, the total flux can be at once determined. This arrangement has proved to be both convenient and accurate. The method was then used for the determination of hysteresis loops of transformer cores, but great skill was required in the manipulation of the water resistance "chopper" switch which was used for the control of the current. The authors have made a distinct step forward in devising the connections shown in Fig. 11, as this makes it possible to pass from one end of the loop to the other without a break. A fairly obvious modification of Fig. 12 allows the use of two ordinary carbon rheostats by the insertion of an insulating plate midway in each. Without doubt the complete solution of the problem turns upon the production of a rheostat enabling a perfectly continuous adjustment of resistance to be made at any speed the experimenter desires. Various forms of liquid resistances have been tried in the laboratories of the East London College; but difficulties due to polarisation of the plates, particularly during the moment of change of polarity when passing one another, cause disturbing variations in the current, and for the present this method has been abandoned. From the results of actual work I consider that for currents above, say, 10 amperes the carbon resistances are the best, but for small currents probably a wire wound spirally with two good travelling contacts would be more satisfactory. It would be of interest if the authors would furnish us with some idea of the degree of accuracy which they expect to obtain in the tests in duplicate experiments—as to agreement in time taken in passing from one end of the loop to the other for the same limits of H, and also similar data with regard to area of loops. Further, what form of handle they consider most satisfactory for the proper adjustment of the rheostats. Unfortunately, all these tests, when they have to be compared Mr. Morris.

Mr. Morris. with those made with alternate currents, require a knowledge of the "form factor" of the current wave for the purposes of strict comparison. With reference to the authors' remarks on the Steinmetz index, experimental results obtained in my laboratories on actual transformer cores confirm their results, in that over the normal range of transformer induction densities, the index 1·5 is nearer the truth, although this index is considerably greater both for lower and higher induction densities. These results are also in accordance with Professor Ewing's classic work on this subject, published in 1893, which was carried out on small ring stampings of sheet iron. In conclusion, I would congratulate the authors on their application of this method of constant induced voltage to the determination of the magnetic properties of small samples of iron, these tests being, as is well known, very laborious when carried out by the methods previously in use.

Dr. Waghorn. Dr. J. W. WAGHORN (*communicated*): The method of measuring power factor which the authors have called the 3-point wattmeter method, and which, as Dr. Sumpner has pointed out, was described by Macalister some two or three years ago, is the most convenient and accurate, not only for circuits of 2-phase or 3-phase motors or transformers, but for any single-phase circuit where access can be had to a third circuit, in which the voltage differs in phase by a known amount. The difference between the expression I recently quoted for a 3-phase system,* and that which the authors use, obviously arises from the angle of lead or lag being measured from the phase of the E.M.F. in the line in which the current coil of the wattmeter is placed in my expression, and upon the resultant E.M.F. between the two line voltages in that of the authors. The latter is certainly better for the general case of the determination of the power factor of, say, a choking coil which is inserted between two live wires of a 3-phase system, the third line being only used as a reference point for the wattmeter readings. In such a case 30° must be added or subtracted to give the usual meaning to the value of ϕ determined from the expression I used. The easy determination of whether the phase difference represents a leading or a lagging current is, as the authors point out, a merit of the method.

Mr. Lamb. Mr. G. C. LAMB (*communicated*): I am interested to see that the milli-voltmeter method of measuring hysteresis loss has been found suitable for such small things as iron specimens. The experiment as regards small transformers is one which has been regularly done in my laboratory.

Mr. Atchison. Mr. A. F. T. ATCHISON (*communicated*): The employment of the "characteristic triangle" of a transformer is very useful, as it combines the resistances and leakage reactances of the primary and secondary into an equivalent resistance and reactance respectively, and thus enables the regulation on different loads to be pre-determined by a vectorial subtraction of the "equivalent" impedance drop from the constant primary applied voltage. It is especially satisfactory to know that the results so obtained are in close agreement with those obtained

* *The Electrician*, vol. 56, p. 977, 1906.

by other methods; as in the case of the regulation of alternators, for instance, the results obtained by this type of treatment cannot always be relied upon, owing to the large numbers of secondary effects which should be taken into account. The connections for the "standard test" suggested by the authors appear to have been worked up into a very convenient form, enabling all the required adjustments to be made easily. The use of a 3-phase supply with the regulating contact for varying the phase angle is very ingenious, and the connections of the secondary of the auxiliary transformer, for, as it were, averaging the disturbance of balance in the differential test, should give more accurate results for the losses—just as in the Hopkinson-Kapp differential test on direct-current machines, the field of one should be strengthened as the other is weakened, in order to average the iron loss. The "method of constant induced voltage" for determining magnetisation curves and hysteresis loops certainly does away with many inconveniences of the older ballistic methods, and is now, I believe, used to a considerable extent. For the determination of the hysteresis loop of transformer cores, however, I should strongly advocate the ingenious oscillograph method devised by Dr. Morris himself and Mr. Catterson-Smith, when such an instrument is available, as the loop may be different, when the core undergoes a slow cyclic change, from that obtained with reversals of the normal frequency of the transformer. Perhaps Dr. Morris could say whether this difference is of appreciable importance? There are many other ingenious things in the paper for facilitating the experimental part of the work, not the least of which is the "3-point wattmeter method" of measuring power factor, which seems a useful alternative to the somewhat cumbersome methods which are in use. Mr. Atchison.

Mr. G. A. LISTER (*in reply*): Dr. Morris and I are fortunate in that both Professor Kapp and Dr. Sumpner are present, and have taken part in the discussion. Dr. Sumpner criticised our application of the Hopkinson or differential test to transformers on the ground of its complication, and suggested that a simple measurement of the iron losses and the short-circuit test would in the majority of cases be sufficient. These tests, however, require exactly the same instruments as those shown in Fig. 4, and unless the 3-point wattmeter method of determining current be adopted, the short-circuit test will require an ammeter in addition. On the other hand, the combination of the two tests in the manner described enables the regulating properties, and also the heating of the transformers, to be readily determined, and these latter qualities are probably more important in the case of transformers than the efficiency. Professor Kapp has pointed out an excellent method of conducting the differential test when a special testing transformer is not available. For core losses it is quite satisfactory, the mean of the wattmeter readings giving the iron loss for the standard flux density with great accuracy. The drawback is the necessity of taking two readings. But the method would not be so satisfactory in the heating test, as, unless the connections were reversed periodically, one transformer would heat either considerably more, or Mr. Lister.

Mr. Lister. considerably less than the normal, and this would falsify the measurements of copper resistance. When making heating tests, it will be found that the difference in the readings of thermometers placed in the oil, or in proximity to the core, will clearly indicate which transformer is working at the higher voltage. The use of the middle point enables a mean value of the heating closely approximating to normal conditions to be obtained. A testing transformer seems to be necessary also on account of the variable voltages required. One such as that described in Section 8 of the paper will certainly give more satisfactory results than a plain testing transformer and a resistance for regulating the voltage.

Dr. Morris. Dr. D. K. MORRIS (*in reply*): I am much interested in the remarks of Professor Hay on the effect of non-uniform flux in samples on the hysteresis loss measured. In the test samples used by Mr. Lister and myself, the radial depth of the ring is very small—sufficient iron being obtained by extending the sample axially in the form of a tube. The effect would be negligible in such samples. A variety of methods have been described by Mr. J. T. Morris for carrying out hysteresis tests by the method of constant induced voltage. A good rheostatic arrangement for gradually effecting the reversal of the current is wanted; but we have found that with the two devices put forward in the paper—viz., the compound shunt giving net ampere-turns and the short-circuited secondary winding into which is inserted an opposing E.M.F.—one is enabled to get correct results even when the control of current is relatively imperfect. The arrangement of carbon rheostats for working the tests from only two supply terminals suggested by Mr. Morris is very practical. Tests made by the new method are found to agree, and they bear repetition if properly taken, as well as those made ballistically. When comparing magnetic qualities by the slow method with those derived from alternating-current measurements, a knowledge of the form factor is only needed for the permeability. Hysteresis can be compared independently of the form factor, but depends probably on the higher harmonics of the E.M.F. wave. So many observers have found the hysteresis loss to vary almost exactly with the 1·5th power of the induction in the region of maximum permeability that it almost suggests there may be some physical reason that the loss should be proportional to $\sqrt{(\text{flux density})^3}$ in this region. (See Appendix.)

BIRMINGHAM LOCAL SECTION.

A SIMPLE METHOD OF MEASURING SPARKING VOLTAGES.

By E. A. WATSON, Student.

(*Paper read April* 25, 1906.)

This paper is the outcome of some experiments which have recently been made by the author in order to determine the length of spark corresponding to various direct-current voltages. The method of measurement is believed to be new, and its chief feature is the entire elimination of any measuring instruments subjected to the working potential, and the consequent simplification of the high-tension circuit. For the measurement of very high voltages when using direct current the method of employing transformer ratios with a voltmeter in the low-tension side, as practised for alternating-current work, is not available, and recourse is generally had to the use of electrometers or other instruments employing electrostatic attraction. These instruments are, however, not satisfactory for voltages of the order of 30,000 and upwards, chiefly on account of the difficulty of satisfactory insulation, while the method about to be described can be used up to the highest direct-current voltages that it is possible to produce.

The principle of the method is as follows : If a condenser be connected to a direct-current source of supply, a current flows into it and charges it, the inflowing quantity depending on the capacity of the condenser and the voltage of supply. If a spark-gap is so arranged that as soon as the condenser is charged to a certain voltage it shall spark across the gap, the condenser will automatically discharge itself and will continue to charge and discharge so long as it is thus connected. Let the number of sparks occurring per second be noted, and also the current flowing into the condenser. If this current is divided by the number of sparks per second we have the quantity per spark expressed in coulombs. Dividing this by the capacity of the condenser, we have the potential difference at which that spark occurred, or the potential at which the air broke down.

We therefore require to know the charging current, the frequency of sparks, and the capacity of the condenser. The capacity can be measured once for all ; the number of sparks per second is readily

obtained by counting, and the only difficulty lies in the measurement of the charging current. It is evident that this cannot readily be done by placing any ordinary instrument in any part of the circuit which is at a high potential, as there would be not only a very great possibility of errors produced by static fields, but it would require a very special instrument indeed to stand the voltage; hence the arrangement shown in Fig. 1 has been adopted.

In this arrangement two condensers are used placed in series. Between the condensers is placed a galvanometer or micro-amperemeter, and the spark-gap to be tested is connected across their outer coatings; the spark-gap being connected to a source of supply which, for reasons to be explained later, is preferably a Wimshurst Influence Machine. Across the galvanometer is placed a small auxiliary spark-gap of about 1/100-inch opening, and between this and the galvanometer are placed two small choking coils, which should not contain iron. These simply consist in the author's case of 500 turns of No. 30, wound into a coil of about 2 ins. diameter.

The object of the auxiliary spark-gap is as follows: When the condensers are charging, a certain quantity of electricity passes through the galvanometer, being simply the charging current of the condensers. When these discharge, there is of course an exactly equal flow of current, which, if it passed through the galvanometer, would give it an equal deflection in the opposite direction, so that the net reading would be zero. But the discharge from two condensers is very sudden, and generally of an oscillatory nature. It cannot, therefore, pass back through the galvanometer and choking coils, but passes entirely across the auxiliary spark-gap. Thus the galvanometer measures only the charging current, and not the discharge of the condensers, and gives a steady deflection.

It will also be seen that, with the galvanometer placed as it is symmetrically as regards both poles of the spark-gap, it will be at earth potential, and consequently no errors due to static charges can be introduced, neither need any special precautions be taken with respect to insulation of the instrument; in fact, it is just as well to earth the galvanometer winding at some point, and thus conduct away any stray charges which may accumulate.

In addition to the advantage of having the galvanometer at earth potential, the position in which it is placed has the advantage of eliminating errors which might be produced due to leakage off any part of the high-tension circuit; if, for example, the galvanometer were placed in the charged portion, it would read not only the charging current of the condensers, but also any leakage current from the electrodes, and the charging current of electrodes and spark-gap. Hence the reading would be too high, and would give false values of the voltage. Placing the galvanometer in its present position, however, it simply measures the charging current of the condensers themselves, and takes no account whatever of any leakage which may occur, nor of the charging current of any other part of the circuit.

In order to ascertain whether the auxiliary spark-gap had any effect

upon the results, readings were made with different auxiliary gaps, and it was found that, over a range far exceeding anything which would be necessary, the error produced was certainly within 0·5 per cent. The gap should therefore be made as small as possible short of actual contact. Probably 0·01 in. is a fair value. It should be very small compared with the length of the main spark-gap.

The advantage of using a Wimshurst machine for the supply is that, owing to the peculiar characteristic curve of this machine, the current output is almost entirely independent of the voltage at which it is worked. This has a double effect. Firstly, the current being constant, we only require a calibration of the galvanometer at one point of the scale, and can hence insure greater accuracy than if the deflection varied over a considerable range; and secondly, the charging current of the condensers does not appreciably fall off as they charge up, as it would do in any other case: for example, if the source of supply were, say, a high-tension direct-current generator charging through a high resistance, the current entering at any time would not be constant, but would be greatest when the condensers were empty, falling to zero when their potential reached that of the supply.

The size of condensers to be employed will depend upon the size of machine available for the supply of current, as the condensers must be so proportioned as to permit of easy counting of the sparks. An ordinary two-plate Wimshurst will give currents up to 20 micro-amperes, and with this value of current, condensers of a capacity of about 0·0005 micro-farad are very suitable. In the author's case the two condensers in series had a capacity of 0·0003352 micro-farad, this being, of course, half the capacity of a single condenser. The condensers must have first-rate insulating properties, glass well varnished with shellac forming an excellent dielectric.

In order to measure the charging current, either a mirror galvanometer may be used or a direct-reading micro-amperemeter such as may now be obtained.

The voltage is arrived at as follows: The time, T, for 100 sparks is measured by a stop-watch. Let C be the current in micro-amperes and K the capacity in micro-farads of the two condensers in series. The current in amperes will be $C \times 10^{-6}$ and the capacity in farads $K \times 10^{-6}$. The charge per spark will be $\frac{CT \times 10^{-6}}{100}$ coulombs, and the voltage will be $CT \times \frac{1}{100\,K}$.

Thus we have only to multiply the current in micro-amperes by the time of 100 sparks, and then multiply by the constant $\frac{1}{100\,K}$ in order to obtain the breakdown voltage of the gap.

In order to obviate any errors which might be produced by the residual charge in the condensers, it is advisable to let a few sparks pass before beginning to count. The condition of the circuit at the end of the hundred sparks will then be the same as regards residual

charge, etc., as at the commencement, and any residual effect will eliminate itself.

It is to be noted that this method gives the average breakdown voltage for any distance. Slight variations in the voltage occur, which are due probably to alterations in the condition of the air, amount of moisture and dust present; and also, possibly, to air currents and the presence of other sparks in the neighbourhood. As, however, the time is taken for a number of sparks, an average value of the voltage is obtained.

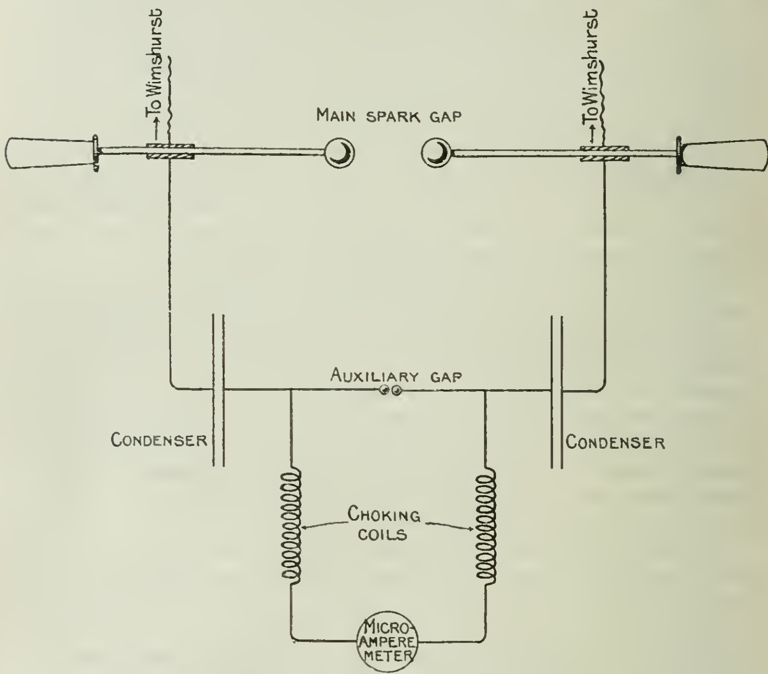


FIG. 1.—Arrangement of Apparatus.

RESULTS OF EXPERIMENTS MADE BY THE METHOD.

General Conditions.—The measurements were made in the University of Birmingham Electrical Engineering Laboratory. The barometric pressure at the laboratory varied from 29·4 ins. to 30 ins. The temperature was very nearly constant at 16° C. throughout the experiments. The condition of the air throughout was dry, no rain having fallen for some time. The light in the room in which the experiments were made was diffused daylight, but was rather strong at times; it fell endways on the spark-gap, so that one electrode was exposed to it while the other was not. It was found, as shown by Hertz,* that when daylight fell on the negative electrode the voltage required for a given spark length was slightly lowered. This was more especially noticeable when the nega-

* *Wiedemann's Annalen*, vol. 31, p. 983.

tive electrode was a flat plate; when it was a ball the effect was much less and was practically negligible. For the best results the experiments should doubtless have been carried out in a darkened room, but as this is not a condition which would occur in practice, it would have been perhaps a needless refinement.

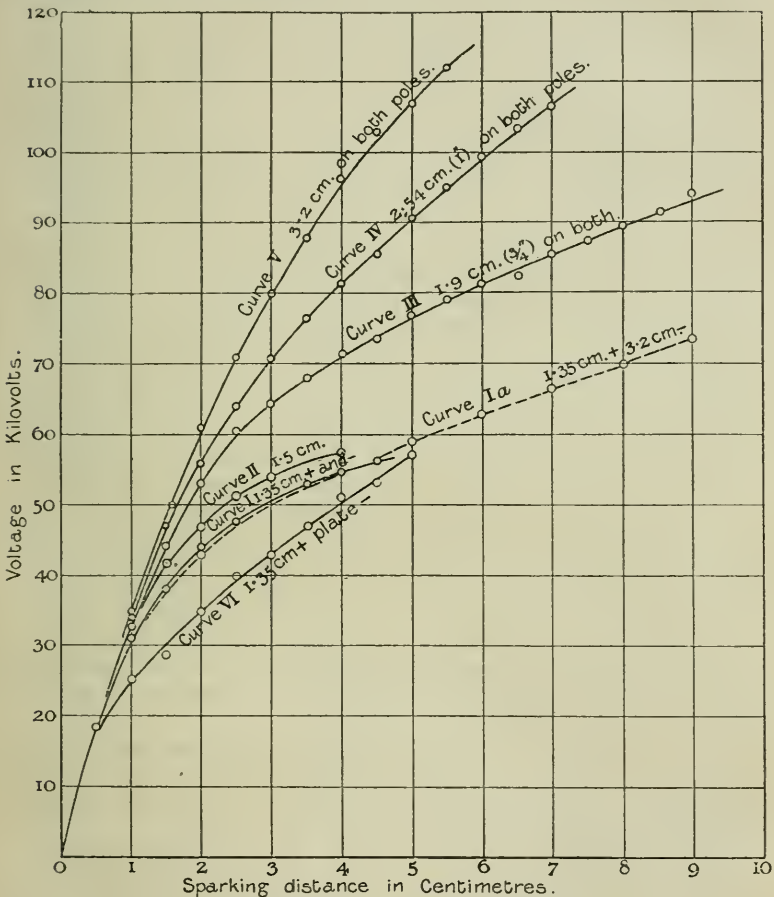


FIG. 2.—Spark Length Voltages for Different Electrodes.

Apparatus Employed.—The source of supply was a 22-inch two-plate Wimshurst machine, driven by an electric motor at any required speed. The condensers were two Leyden jars, whose capacity in series was 0·0003352 micro-farad; they were carefully tested for leakage by opening the gap beyond the sparking distance in order to determine whether any current would flow through them and so deflect the galvanometer, but no deflection was obtained. Hence it is safe to conclude that no errors due to leakage through them could have taken

place. The galvanometer used was an Ayrton-Mather moving coil reflecting type, with universal shunt. Measurements of the deflection would be readily made to 1 part in 500. The galvanometer was standardised about twice a day by means of a potentiometer with cadmium cell as standard; the calibration changed very little throughout the entire range of experiments. Measurements were first made, using different sizes of electrodes, in order to determine to what extent the values were affected by their size and shape. The electrodes used were brass balls cleaned and polished. The curves obtained are shown in Fig. 2, from which it will be seen what a great effect the size of the electrode has upon the voltage required to produce a spark of given length, more especially towards the higher values.

The usual gap on which measurements are made is, of course, the point or point and plate, but this was found to be useless when subjected to high and steady pressures, as the leakage from the points became excessive, and it was impossible to get any definite breakdown point at any spark length greater than a few millimetres; the point of breakdown must also depend, to a great extent, upon the sharpness of the point, and it is believed that, given a mathematical point, discharge would occur with zero pressure. On the whole, the writer is not in favour of the use of needle points for standard spark-gaps; at all events for direct-current work, definite sized balls are probably better. When using two balls either of equal or unequal size perfectly definite points of breakdown were found and much better results obtained.

Another noticeable feature is the falling over of the curve, especially for small balls, disproving the statement which is still sometimes found in books, that the sparking distance is proportional to the pressure.

The curve does not appear, however, to fall completely horizontal, but to become a straight line with a uniform slope upwards. This is well shown in the dotted line curve marked I.*a*, which was taken with a positive ball 1·35 cm. diameter and a negative one 3·2 cm. in diameter, and it is also shown in Curve III., which was taken with two equal sized balls, each 1·9 cm. diameter.

In one or two cases, at very high voltages, a slight tendency for the curve to turn upwards again has been observed when using balls of unequal size. The explanation of this effect is not clear, but a similar one has been observed by Kintner.*

When using small balls—*e.g.*, 1·35 cm.—the limit of the curve was reached by brush discharges occurring. When this takes place all definite sparking ceases, and measurements cannot be taken. This brush discharge always occurs on the negative ball first when they are of equal size, and if this is replaced by a larger one, the voltage and spark length can be carried much higher before brushing commences. In order to determine what was the controlling factor in such a case—*i.e.*, with balls of unequal size—measurements were made using a 1·35 cm. positive combined with various sized negatives from 1·35 cm. up to 3·2 cm. The results showed that over a considerable

* "Measurements of High Electrical Pressures," Kintner, *Electrician*, vol. lv. p. 702.

range the sparking voltage for any given distance was the same whatever the size of the negative electrode. Up to about 4 cm. gap the 1·35 cm. positive ball gave the same results whichever negative was used. Above 4 cm., using a 1·35 cm. positive and also a 1·35 cm. negative, brushing occurred, and the curve could not be carried further, but using a 1·35 cm. positive combined with a 3·2 cm. negative the curve was carried up to 9 cm., as shown by Curve I.*a*, this curve being practically a continuation of Curve I., only not fallen over quite so much.

Experiments made with the polarities reversed—*i.e.*, with the 1·35 cm. ball negative and various sizes positive—showed that here again the curves agreed fairly well with the one for 1·35 cm. on both poles, although in this case, owing to excessive brushing, the voltages could not be taken up very high.

Hence the conclusion is reached that within moderate limits the sparking voltage of any gap is determined by the size of the smallest electrode, and the other one may be varied within reasonable limits without appreciably affecting the result. If unequal sized electrodes are used it is advisable that the largest one should be placed on the negative pole, otherwise any advantage accruing from its use is lost. In fact, placing it on the positive pole is worse than having no large electrode at all, and causes brushing to commence much sooner. This conclusion, it is to be noted, cannot be carried too far; for example, with a ball and plate, the ball being 1·35 cm. diameter and on the positive pole, the plate 6 cm. diameter and on the negative pole, the curve obtained (Curve VI.) does not agree with that obtained by using two unequal sized balls, the positive being 1·35 cm. diameter, whereas if our former conclusion held for spheres of infinite radius it should do so.

The curve for the ball and plate, it is noted, falls below Curve I. for the lower values when the ball is close to the plate, and approaches it when the ball is at a considerable distance.

This effect is just noticeable also when using a small positive ball (1·35 cm.), combined with a large negative one (3·2 cm.), a slight falling under at low values being apparent (Curve I.*a*). Still, it may safely be concluded that for sizes of one electrode varying from equal to the other up to twice its diameter, the spark length voltage is unaffected.

The other curves in Fig. 2 give the sparking voltages for other sizes of balls. In each case the positive and negative electrodes are equal in size. The voltage could in these cases be carried much higher than in the case of the small balls, as brushing does not occur so readily. With the 2·54 cm. and 3·2 cm. electrodes the limit was not the brushing, but the occurrence of disruptive discharges over the condensers. With condensers made to stand the voltage the figures could doubtless be taken much higher, as there is no theoretical limit to the voltage obtainable from a Wimshurst machine except such as is imposed by leakage or disruptive discharge.

Curves for intermediate-sized electrodes can be obtained with very fair accuracy by increasing the ordinates of the given curves in the

ratio of the diameters of the electrodes employed to those given. If alternating voltages are required the direct-current voltages for any gap must be divided by $\sqrt{2}$, as the striking distance is governed by the maximum voltage and not by the R.M.S. value.

The voltages given are in all cases in kilovolts, the sparking distance being in centimetres, and the sizes of the electrodes are centimetres diameter. A table of the most important results is given below.

Table of Sparking Voltages in Kilovolts.

Distance.	1·35 cm. Balls (·53 in.).	1·9 cm. Balls (¾ in.).	2·54 cm. Balls (1 in.).	3·2 cm. Balls (1·26 in.).
Cm.	Kilovolts.	Kilovolts.	Kilovolts.	Kilovolts.
1·0	31·1	32·4	34·05	35·0
1·5	38·0	44·2	46·95	47·5
2·0	44·1	53·0	55·6	61·0
2·5	47·5	60·45	64·0	71·0
3·0	50·5	64·5	70·7	80·0
3·5	52·9	68·0	76·6	87·9
4·0	54·5	71·5	81·4	96·4
4·5	56·2	73·6	85·7	102·9
5·0	Brush discharges occurred.	76·9	90·6	107·1
5·5		79·2	95·0	112·0
6·0		81·4	99·2	Disruptive discharge over condensers.
6·5		82·5	103·2	
7·0		85·6	106·6	
7·5		87·4	Disruptive discharge over condensers	
8·0		89·6		
8·5		91·5		
9·0		94·2		

The author recognises that this method of measurement has certain limitations, as, for example, its inadaptability for alternating-current work, but as high-tension continuous current is now apparently going to occupy a prominent position, he hopes that it will be found of some use. Its great feature is the simplicity of apparatus and the ease with which all the measurements may be carried out, giving, as it does, a measurement of voltage derived from the current and capacity units, and obviating any of the ordinary complicated arrangements necessary when using voltmeters on high-tension circuits. Of course, it is not suggested that the method is suitable for use as a voltmeter; that is entirely out of the question. The real use of the method lies in the standardisation of spark-gaps by its means, or possibly in the standardisation of extra high-tension electrostatic voltmeters.

In concluding, the author wishes gratefully to acknowledge the help and suggestions received from Dr. D. K. Morris and Mr. G. A. Lister during the progress of the work, and also in the preparation of the paper. He is also indebted to the Birmingham Natural History and Philosophical Society for the loan of the Wimshurst machine.

DISCUSSION.

Mr. M. J. E. TILNEY (*communicated*): There are one or two points in Mr. Watson's paper that do not quite agree with the results I have obtained in practical working with direct currents at pressures at or about 2,500 and 3,000 volts. We have had at several of our stations transmissions of three miles or so at a normal working pressure of 2,500 volts, and we have installed spark-gaps to deal with the surge rises that take place when short-circuits or big over-loads occur either in the high-tension cables themselves, or on the low-tension sides of the transformers. These spark-gaps are of the disc type, and have, I think, 12 discs giving 11 gaps, each of which is certainly not less than $\frac{1}{32}$ inch; this gives a total gap of about 0·344 inch, or approximately 0·87 cm. In one or two cases this gap has actually sparked across without a surge at all, owing to the atmosphere being very damp on account of a leak of steam, when the arc held. Mr. H. W. Fisher, in a paper read before Section D of the St. Louis Congress, 1904, gave a sparking distance for 10,000 volts of 0·54 inch or rather over 1·25 cm., and though this is from a point to a disc, I can hardly reconcile the results with those obtained by Mr. Watson. The question of the proper gap to use for high-tension direct-current transmission is so important, if much progress is to be made in its use, that I hope Mr. Watson may be enabled to continue his experiments, and I would like to suggest to him that it is possible that the results he is getting, and would get, from the use of a Wimshurst machine may be very widely different from what he would get either from a single direct-current generator wound for, say, 3,000 volts, or from a series of 500-volt machines connected in series. I fully realise that it is not so simple to take tests in this way, and it is not so safe, but engineers using these high direct-current pressures want results that they can rely on in practice, and I hope I shall be excused for pointing out what is evidently a serious difference between laboratory and station results. Mr. Tilney.

Professor G. KAPP: Mr. Watson has made some admirable measurements on the dielectric strength of air. This is quite a different thing from the distance which would hold an arc that had been set up in a damp atmosphere, to which Mr. Tilney had referred. Mr. Watson's results must not be compared with those obtained by the use of a number of small gaps in series, as the conditions are very different. The figures given in the paper show a fair agreement with those obtained by other experimenters, considering the different conditions under which the experiments must have been made as regards barometric pressure, temperature, etc., and as they give rather lower values of the sparking distance, it will be safe to trust them. The results are important in connection with direct-current high-tension transmission, as they show that the liability to brush discharge increases with a reduction in the size of the conductor. Professor Kapp.

Mr. E. A. WATSON: In reply to Mr. Tilney, I have very little to add to Professor Kapp's remarks. The voltages with which Mr. Tilney deals are rather below those I have used, which are of the order of Mr. Watson.

Mr. Watson.

10,000 volts and over. I can quite understand that Mr. Tilney would get phenomenally long sparks in an atmosphere rendered damp by a leak of steam, as the particles of water form a number of conducting links across the gap, thus permitting of the passage of a spark. Once a spark has passed, a different set of conditions holds, and the question of continuance or non-continuance of an arc has nothing to do with the breakdown voltage of the gap.

With regard to Mr. Fisher's figures, these measurements were, I believe, made with alternating current, and, of course, an alternating E.M.F. of 10,000 corresponds to a steady E.M.F. of 14,000 volts. Moreover, it is a generally recognised fact that the gap between a point and a disc is the easiest possible for a spark to jump. When one considers the great effect upon the sparking voltage produced by altering the diameter of the electrodes from 1·35 cm. to 3·2 cm., it will not be very difficult to see that for a point, which we may regard as a sphere of zero radius, we may reasonably expect a greatly decreased voltage for the same length of spark.

As to the use of a Wimshurst machine for the making of the tests, and the question as to whether the same results would be obtained as in using high-tension direct-current generators, I fail to see that any difference would result. Of course, once a spark has passed and an arc is set up, matters are entirely different, but the actual breaking-down voltage of a spark-gap can only depend on the dielectric stress, which in turn depends on the voltage applied to the electrodes, and this voltage will surely be independent of the way in which it is produced, whether by electrostatic or by electromagnetic means.

With regard to the problem of brush discharging pointed out by Professor Kapp, it will be a very serious difficulty in connection with high-tension work. The leakages in the cases noted in the paper are of the value of about 18 micro-amperes, that being the current given by the machine, and it will be found by calculation that this means a loss of from one to two watts, depending on the voltage. In all probability, the leakage is greater than would be the case from a wire which is strung at a considerable distance from any other objects, as the potential gradient is much steeper. Also the leakage will, in all probability, not take place so easily off a cylinder as off a sphere of the same diameter, so that the trouble due to leakage may not really be as bad as it seems.

STEAM TURBINE DYNAMOS.

By A. G. ELLIS, A.C.G.I., Student.

(*Paper read before Students' Section, Jan.* 31, 1906.)

The introduction of steam turbines as direct-connected prime movers for electric generators has led, by reason of the necessarily high speeds involved, to considerable departures and new problems in the design and construction of the dynamo electric machinery which do not arise when dealing with the lower speeds hitherto employed. Problems have not only arisen for the dynamo maker, but also for the central station designer, who encounters problems incident to the great floor-space economy of turbo-generators as compared with the low or even so called "high-speed" engine, difficulty actually being found in providing sufficient accommodation for the boilers required for a single turbine unit. This has called for such lay-outs in turbine central stations as the double-decked boiler house, as installed at the Chelsea Power House of the Underground Electric Railways, and also the arrangement of a series of short boiler houses running at right angles to the engine-room, as in the new stations of the Yorkshire and Lancashire Electric Power Companies.*

Considering the steam turbine as a prime mover, although the question of its possessing a better steam economy than the piston engine is still a debatable point,† it presents many other advantages, such as economy in space and lubrication, and even turning moment, which render it advantageous. The last item is of importance for alternator driving from the standpoint of parallel running. "Hunting" with paralleled alternators may be ascribed primarily to variations in the turning moment of the prime mover. Here the turbine has all its own way, giving as uniform a turning moment as is desirable. Voltage variations in the electric circuit are due to surges of current between the machines, set up by swinging in and out of phase, by reason of turning moment variations. If one examines the relation between the angular displacement of the prime mover and the phase angle displacement in the electric circuit, one sees a further reason why parallel running with turbine drive is good.

Consider the case of the two following alternators :—

(1) 50-cycle, 4-pole, 1,500 r.p.m., turbine-driven.
(2) 50-cycle, 40-pole, 150 r.p.m., engine-driven.

* The subject of central station design for turbine plants has been fully treated by Messrs. C. H. Merz and McLellan—see *Journal of Institution of Electrical Engineers*, vol. 33, p. 696.

† See "Steam Turbine Engineering," T. Stevens and H. M. Hobart, 1906.

In Case 1 there are two cycles per revolution and one cycle occurs during a displacement of the rotor of 180°.

In Case 2 there are twenty cycles per revolution, and one cycle corresponds to a displacement of the flywheel of 18°.

Now supposing the prime mover swings 2° (the usual maximum allowance), this corresponds in the electric circuit to $\frac{2}{180} = 1 \cdot 11$ per cent. of a period, or a phase swing of 4°.

In Case 2 the corresponding phase swing is $\frac{2}{18} = 11 \cdot 1$ per cent. of a period, or 40° in the electric circuit.

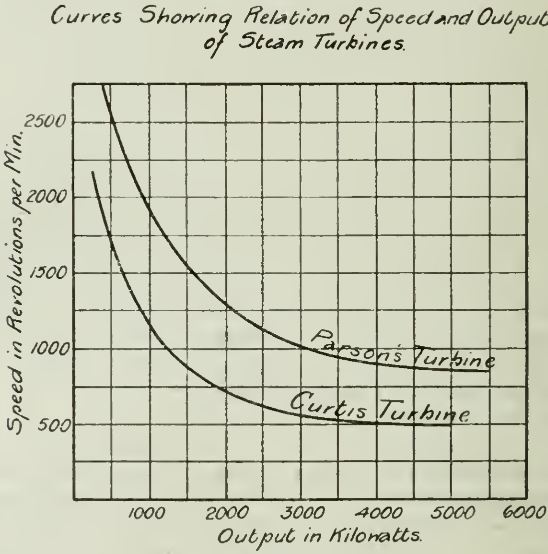


FIG. 1.

Thus in the engine set, for a given angular displacement of the prime mover, the phase shift in the electric circuit is ten times what it would be in the turbine set. The surging currents and voltage fluctuations are dependent upon this angle, and considering that a turbine never approaches an angular irregularity near 2°, it is very apparent why turbine sets should run well in parallel with one another or with engine-driven sets. Incidentally, the trouble of getting engine cranks into step, which is often necessary, does not enter into turbine driving.

Until recent years, before the steam turbine had been brought to a stage of commercial possibility and adaptability as a prime mover for electric generators in large as well as in small sizes, the highest speeds met with did not exceed about 300 to 400 r.p.m., these being about the speeds of what are known as "high-speed" engines. Such speeds, although high for reciprocating engines, are medium speeds

under the category of electric machines, and, in fact, their characteristics do not present any radical difference from the "low-speed" machines of from 80 to 120 r.p.m., even in large sizes.

High speeds have been employed in cases of belt driving, but only for comparatively small machines, in which cases, moreover, they assume quite normal proportions. A small output requires small general dimensions which can be normally proportioned to give ordinary properties electrically and mechanically. We shall consider later on the relation between the output and the proportioning of the machine on its properties. Generally speaking, the higher the speed the more the design departs from the normal both as to dimensioning

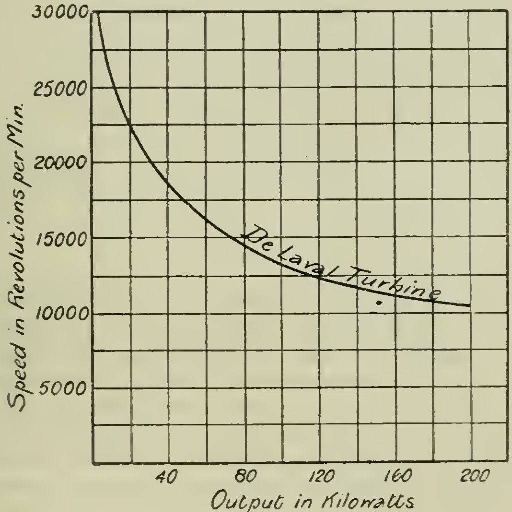


FIG. 2.

and properties and the more difficult is its design problem, especially when large outputs are required with high speeds.

Fig. 1 gives a curve showing the average speeds of steam turbines at various rated outputs up to 6,000 k.w. This curve is compiled from a number of machines already in operation, chiefly of the Parsons type (by various makers) and the Curtis (vertical shaft) turbine. The speed is some inverse function of the output, the largest sizes up to 6,000 k.w. run at the lowest limits of speed for steam turbines, *i.e.*, 500 to 1,000 r.p.m., and this speed increases as the rated output gets smaller. Thus the 500-k.w. Parsons turbine usually has a speed of 2,500 r.p.m. In the de Laval turbines, speeds as high as 30,000 r.p.m. are encountered in very small sizes of from 3 to 5 H.P. The actual turbine spindle in the de Laval turbines runs at 10,000 to 30,000 r.p.m. (see Fig. 2), the dynamos being driven through a reduction gearing usually at one-tenth of the turbine speed. There are usually two dynamos side by

side, driven from one turbine spindle. On account of the gearing the de Laval turbine is not made for outputs of more than 300 H.P.

An increase in speed causes a more or less proportional decrease in weight and cost of a dynamo for the same quality of machine. This is true for the lower range of speeds and machines of hitherto normal proportions, but when we come to the high speeds involved in turbine driving it becomes questionable whether the turbine speed is the most economical and suitable for the electric generator. We can obtain some insight into this matter by considering what conditions constitute the limits of the size of a machine for a given output.

Continuous-Current Dynamos.—In continuous-current dynamos the two limits which define the degree of excellence of the machine are, firstly, temperature rise, and secondly, commutation.

Alternating-Current Generators.—With alternators the limits are, firstly, temperature rise, and secondly, voltage regulation.

Each of these limits is usually specified for any machine, and also the efficiency, but of this latter it may be said that it is closely connected with the heating limit, and is generally brought within its required limit if the temperature rise also is so. The heating limit is, of course, common to all classes of electric machinery, but the second limit is peculiar to the class considered. We will consider briefly what may be taken as a criterion for each of these limits.

Temperature Rise.—We cannot attempt here to enter to any extent into the involved question of heating and temperature rise. The two papers by Rayner on "Temperature Experiments at the National Physical Laboratory," and by Goldschmidt on "Temperature Curves and the Rating of Electrical Machinery," read before the Institution last year (*Journal of Institution of Electrical Engineers*, vol. 34, 1905), have added a good deal of useful information on the subject, but much more is still desirable. Viewing the problem generally, the temperature rise is proportional to the total losses in the machine and inversely to the total radiating surface of the parts of the machine in which the losses occur. That is, the rise in the temperature is proportional to the watts lost per unit of radiating surface. The rise is affected by the ventilating qualities of the machine and the velocity of cooling air circulating through it. The total losses throughout the machine can be fairly accurately estimated, and in the case of solid field coils, the radiating surface can be fairly accurately calculated.

But the true radiating surface of an armature, where the seats of the losses are both copper and iron, is a rather indefinite quantity, the iron surfaces in the ventilating ducts and the ends of the armature coils being all exposed to cooling air. It would be fallacious to attempt to determine the total surface of windings and iron from which radiation can take place, and to use such a figure in calculating the temperature rise on the basis of the watts per unit of this surface, multiplied by some constant equal to the rise in temperature, because the ventilating surfaces contribute in such widely varying extent to the radiation of the heat. For instance, the core ducts of a ventilated armature may receive air at a higher temperature than that which

passes the windings, and it is possible, in the case of armatures of great core length, for the ducts at the centre of the machine to contribute very little to the cooling. The velocity of the cooling air may also differ widely in different parts of the machine.

Thus it becomes necessary to work on some surface common to all machines, and the generally accepted practice is to use the cylindrical surface at the air-gap, over the windings. If $L =$ the axial length over windings and $D =$ armature diameter, this surface is $\pi \cdot D\,L$. A good rule for finding L is to take $L = l + 0{\cdot}7\,p$, where $l =$ gross armature core length and $p =$ pole pitch. This assumes that the windings project a distance 0·35 of the pole pitch at each end of the armature, which is not an unusual value in practice. The surface is then $\pi\,D\,(l + 0{\cdot}7\,p)$. The temperature rise may now be taken as a constant times the number of watts lost per unit of armature surface.

For ventilated armatures of ordinary design, the temperature rise (according to Parshall and Hobart) varies from 15° C. to 20° C. per watt per square inch for a peripheral speed of 3,000 ft. per minute (17 metres per second), and from 10° C. to 12° C. for a peripheral speed of 6,500 ft. per minute (36 metres per second). In turbine dynamos, however, we run up to peripheral speeds of the order of 10,000 to 15,000 ft. per minute (55 to 80 metres per second), and sometimes as high as 18,000 ft. per minute (100 metres per second). At these high peripheral speeds a much lower rise per watt per square inch can be allowed, and for the range of speeds quoted above a rise of 3·5° to 8° C. per watt per square inch is more nearly correct.

Thus in the equation $T^\circ C. = K \times$ watts per square inch, the values of K will be :—

Average Peripheral Speed.	Value of K.
17 Metres per Second...	15 to 20
35 ,, ,, ,,	10 to 12
70 ,, ,, ,,	3·5 to 8

Or if $T^\circ C. = K^1 \times$ watts per square centimetre, the values will then be :—

Average Peripheral Speed.	Value of K^1.
17 Metres per Second...	95 to 130
35 ,, ,, ,,	65 to 80
70 ,, ,, ,,	20 to 50

The value of this constant for any particular case must be chosen with regard to the quality of the ventilating system.

The radiating surface of high-speed machines comes out small by reason of the small general dimensions, but the total losses for a reasonable efficiency are about the same as for a machine of the same rating at a lower speed, and thus the heating constant (watts per sq. inch) is high. It is not desirable to decrease this by increasing the dimensions, or by reducing the losses, which is not called for so far as the efficiency is concerned, as either of these proceedings would entail

increased weight and cost. Hence we are led to provide very liberal ventilation in turbine machines.

Examination of any high-speed machine will demonstrate the amount of ample provision made for ventilating. We will refer to a few particular schemes later on. In the writer's opinion, some idea of the ventilation of the armature is given by the ratio of the net core length to the gross core length. For instance, if this ratio is 0·7, then, allowing 10 per cent. for core plate insulation, 20 per cent. of the core length is occupied by air ducts, or there is 1 cm. duct for every 4 cms. of iron. The width of duct employed varies from 1 to 2 cms. and the distance between ducts from 3 to 5 cms. The ratio of net to gross core length in such cases is 0·7 to 0·8, the lower of these figures representing a liberally ventilated armature. Wide ducts are preferable, but two at 1 cm. wide would probably be better than one at 2 cms.; the minimum width of duct is not advisably less than 1 cm. for any other than small machines.

The heating constant in such machines at high peripheral speeds can be pushed very high, *i.e.*, from 0·75 to 1·0 watt per sq. cm. (about 4·5 to 6·5 watts per sq. inch), and, in cases, even higher than this. It will be of interest to quote an example.

The following figures relate to a 1,500-k.w. rotating field alternator running at 1,000 r.p.m. with a peripheral speed of 64 metres per second :

Gross length of armature	58 cms.
Number of ventilating ducts	7
Width of each duct	1·25 cms.
Distance between ducts	6 cms.
Ratio of net to gross core length	0·75

The estimation of the full load losses and the radiating surface gave a heating constant of 1·1 watts per sq. cm. (7 watts per sq. inch). After a run of $5\frac{1}{2}$ hours, of which the last 3 hours were under full load conditions, the maximum observed temperature in the armature core ducts was 45° C., giving a rise of 24° C. (atmosphere being at 21° C.). This corresponds to a rise of 3·4° C. per watt per sq. inch, or 22° C. per watt per sq. cm., which are very low values.

Of course, the actual temperature existing in the body of the armature is greater, and this particular machine was provided with cups on the rotor to churn the air through the machine. Reference to these special ventilating devices will be made subsequently.

The temperature rise of field windings is a simpler matter to deal with in the case of ordinary field coils, with which one meets on continuous-current turbine dynamos in the ordinary way. But in the case of alternators where the field windings usually constitute part of the rotating system, and the methods of winding and fixing depart widely from the ordinary solid field coil, the case is more complicated.

Amongst the various designs employed are to be found the ordinary field coil construction and variations and developments from

this, until in some cases the field windings are actually carried out similar to armature windings, thoroughly distributed in slots. It becomes necessary to consider each case, or rather type, individually, having regard to the heating constant, the velocity of the moving windings, the conductivity of the material of the coil, the distribution and conductivity of material in contact with the windings, and the ventilating arrangements.

For an ordinary field coil,* when stationary, the rise is of the order of from 60° to 80° C. per watt per sq. inch, or it will heat about 450° C. per watt per sq. cm. of surface exposed to the air.

If cooling air passes the field coils blown from a rotating armature, for peripheral speeds above 3,000 ft. per minute (17 metres per second) this figure may be reduced to an extent of some 25 to 50 per cent., the greater reduction applying in cases of small depth of winding and well-ventilated coils. For field coils of ordinary construction rotating at a mean peripheral speed above 7,000 ft. per minute (40 metres per second) the rise may be 15° to 30° C. per watt per sq. inch, or 100° to 200° C. per watt per sq. cm.

These figures give only a rough idea of the order of the rise, the actual value depending again upon many considerations in any individual case.

In high-speed alternators the number of poles is generally few, from 2 to 8 being customary (the frequency determining this), and there is thus plenty of space between the poles and consequent free access of cooling air.

When the field winding is carried out in slots similar to an induction motor stator winding, it can in some cases be considered as equivalent to a wound armature from the thermal standpoint, although it is generally not so well ventilated, which, together with other points, must be well kept in mind in estimating the temperature rise.

Commutation.—The sparking is determined by the value of the electromotive force in the short-circuited coil at the precise moment of commutation. This is dependent upon the strength of the magnetic field around the conductor at the moment of reversal, and consequently on the actual shape of the current and time curve during the period of commutation. This shape is influenced by such considerations as shaping of the pole tips and armature interference, and is at the present time the subject of much experimental investigation. If the shape of the curve be assumed as portion of a sine curve, *i.e.*, the current treated as reversing like an ordinary alternating current, a value of the mean reactance voltage during the period of commutation is calculable from

* R. Goldschmidt gives 1,500° C. per watt per sq. cm., but this is where the *whole* surface of the coil is taken as cooling surface, and for semi-enclosed medium-sized machines, and the rise measured by resistance increase.—*Journal of Institution of Electrical Engineers*, vol. 34, p. 660.

Dr. S. P. Thompson, in the discussion on this paper, gave a figure of 350 due to Esson, 420 due to Oerlikon Company, and 710 due to Neu & Levine, the latter being by resistance measurement. Parshall and Hobart give 500. On the whole the figures quoted above are consistent with these. See also Rayner, "Report on Temperature Measurements at the National Physical Laboratory."—*Journal of Institution of Electrical Engineers*, vol. 34, p. 613.

the inductance of the coil and the frequency of the reversal. Such an assumption is probably far from correct, but nevertheless it affords a basis upon which all machines may be similarly calculated, and has been found to be a sufficiently good criterion for the commutation pending further experimental results.

The reactance voltage is equal to C × Z, where C = current in the coil and Z = its reactance. The self-inductance can be estimated on the basis of the number of magnetic lines linked with one turn of the coil per ampere. The number of lines per ampere linked with such portions of the conductor as lie embedded in iron (*i.e.*, in the slots) may be taken as 4 c.g.s. lines per cm. of "embedded" length, and for those parts of the winding free in the air (*i.e.*, the end connections), 0·8 c.g.s. lines per cm. of the "free" length.* By estimating the mean length of one armature turn and the amount of this length embedded in iron (= twice the net core length) we arrive at the total number of lines linked with one turn of the coil per ampere flowing. The inductance in henrys = c.g.s. lines × 10^{-8}. If there are t turns per segment, the self-inductance of the coil is $l = t^2 \times$ inductance per turn. The reactance $Z = 2\,\pi\,n\,l$, where n = the frequency of commutation or the inverse of the time of one complete reversal of the current in the short-circuited coil. If v = the peripheral speed of the commutator in cms. per second and b = the circumferential width of the brush in cms., then evidently $n = \frac{v}{2b}$.

We have now all the necessary items for the reactance voltage.

$$\text{R.V.} = C \times 2\,\pi\,l \times \frac{v}{2b} = \frac{C\,\pi\,l\,v}{b}$$

The limiting values of the reactance voltage for sparkless commutation, using carbon brushes, may be taken as 1 to 1·5 volts for small machines, and up to 4 volts for large outputs. This has been exceeded in cases, but practice shows an excess undesirable. For low reactance voltage we can first keep down the frequency of commutation. This can be done by employing low peripheral speed for the commutator, which will then be of small diameter. As, however, the diameter of commutator is usually determined by the lay-out of the machine, not much ground can be gained here. If the diameter is cut very small, the commutator becomes long in order to give sufficient collecting surface, which leads to ugly mechanical results. The diameter is, moreover, limited by the smallest width of segment which can be conveniently manufactured. The next factor in the frequency is the brush width, which should evidently be as large as practicable. This, however, is limited by the number of segments it is permissible to cover. Supposing the brush covers one segment, it short-circuits one coil and the lines linked with the coil are due only to the current flowing in its own turns. If now the brush covers two segments, it short-circuits two coils and the lines linked with one coil are due to the current flowing

* See *Journal of Institution of Electrical Engineers*, vol. 31, p. 189.

in the turns of both coils, and may be double what they were in the first case.

Thus the width of the brush is limited in that it is not desirable to cover more than three segments in order to keep down the self-inductance of the short-circuited coil. Hence we are practically bound down to a certain range of values for the commutation frequency, which in ordinary cases varies from 200 to 800. The other factor which should be minimised is the self-inductance of the coil. We have just seen the effect of the brush width on the inductance, but of more importance is the number of turns per commutator segment. The inductance is proportional to the square of the number of turns, and thus going from one turn to two turns per segment increases the inductance four times. It is thus desirable to keep the turns per segment as low as possible, one or two turns being good practice for machines of moderate size. The number of commutator segments per armature slot also has some bearing on the inductance of the winding, a well-distributed winding being, of course, less inductive. The number of segments should be as large as can be mechanically got into the periphery of the commutator.

Having briefly reviewed the limiting factors to the output, we will now consider what is the effect, on each of these limits, of increasing the speed. So far as temperature rise is concerned, increasing the speed and reducing the dimensions for a given output augments the difficulty of dissipating the heat due to losses, the total losses remaining much the same. This can be provided for by liberal allowance for ventilation, and is in some degree offset by the increase of velocity of the cooling air. By continuing to increase the speed, a point might be reached where the dimensions would be so small that the heating becomes prohibitive and an increase in dimensions would be necessary. Such a state would not, however, be brought about by thermal considerations, as before then other influences, namely, commutation, and mechanical problems step in.

Thus within the practicable range of speeds, the temperature limit can be kept within its bounds without entailing increase in the dimensions and weight. It is to the commutating qualities that the high speed is injurious. An examination of the various quantities involved in the reactance voltage equation will show the desirability of large diameters * and short core lengths from the commutating standpoint. This is due to a combination of several features. With a large diameter a larger number of commutator segments is possible, and consequently for a given number of armature conductors a small number of turns per segment can be employed, giving a small inductance per coil (which is proportional to the square of the number of turns). Shorter core lengths also tend to a reduction in inductance by reason of the shorter lengths of conductor embedded in the iron. These points contribute to a low reactance voltage per segment and good commutation.

* Mavor has shown the reactance voltage for a given output to be inversely proportional to the armature diameter. (See *Journal of Institution of Electrical Engineers*, vol. 31, p. 218.)

Large diameters, incidentally, up to certain limits present better cooling facilities.

The employment of high speeds at once sets a limit on the diameter, as defined by the maximum permissible peripheral speed from mechanical considerations. This imposes conditions which are in direct opposition to the points mentioned above, and this becomes more marked at very high speeds and large outputs.

The choice of the number of poles also bears on the question. The number of poles is limited on the one hand by the frequency of the magnetic reversals in the armature. This, from consideration of the iron losses and the heating, should not exceed from 50 to 75 cycles per second, and should be lower, the higher the flux density in the armature. On this account, with high speeds, the number of poles is required to be small. On the other hand, the number of poles should be so great that the armature ampere-turns per pole are not too high, as this leads to excessive field distortion, which affects the commutation. Here again we have two opposing tendencies, and the employment of high speeds does not improve circumstances. In fact, for high outputs at high speed, an ordinary design is rendered prohibitive, and it is significant that there have been few continuous-current turbo-dynamos built for an output of more than 500 k.w., while alternators have run into thousands of kilowatts. Generally it may be said that, up to a certain limit, a machine for a given output and voltage and of a given degree of excellence will be cheaper the higher the speed. But for speeds above that limit, to maintain the same degree of excellence, the machine will be more expensive.

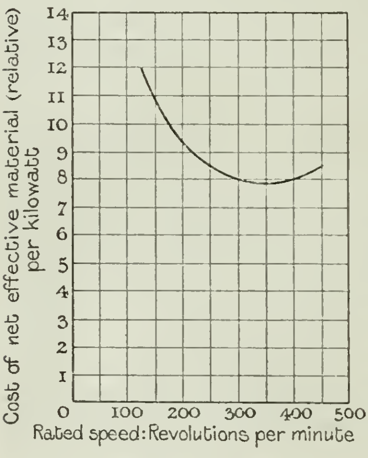


FIG. 3.

Thus it appears that for a given output and voltage there is a certain speed at which the cost of material is a minimum. Such a speed will have a different value for different ratings and voltages. This was pointed out by Mr. H. M. Hobart in the discussion on T. H. Minshall's paper on "High Speed Electric Generating Plant,"* and in view of the significance of the conclusions there stated, the writer has reproduced in Figs. 3, 4 and 5, some curves given in that discussion and the appended conclusions. Fig. 3 shows for a 750-k.w., 1,000-volt continuous-current generator the cost of net effective material as a function of the speed. This shows the most economical speed for this particular

* *Minutes of Proceedings of Inst. Civil Engineers*, vol. 151 (1902–3), p. 97.

case to be 350 r.p.m., but this would be somewhat lower for minimum total works cost per kilowatt, on account of the greater proportion of labour and structural material required for the higher speeds.

Fig. 4 shows values of the speed of minimum cost for various outputs, with due consideration of these points. From this curve it is apparent on comparison with the curves of Fig. 1 that the continuous-current dynamo is inherently adapted to slow speeds, steam-turbine speeds being far above the most suitable for machines of any but small rating.

Following this, the author lays down a principle of design for a group of machines of various speeds, the substance of which is to design the machines all with a constant diameter for all speeds, and to vary the core length inversely as the speed. Thus the peripheral speed will be increased in proportion to the angular speed (up to the

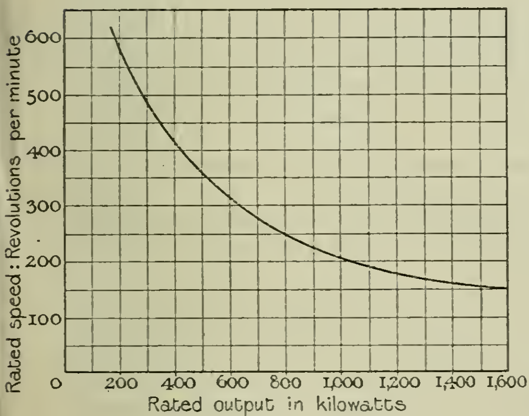


FIG. 4.

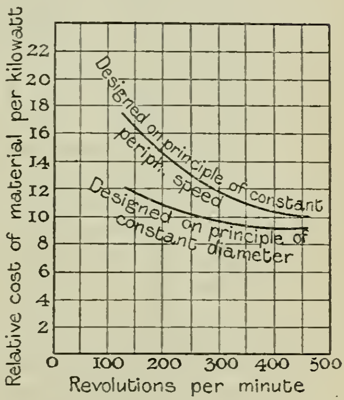


FIG. 5.

mechanical limiting peripheral speed), and such a method will give much more economical results than the hitherto common practice of employing about the same peripheral speed for all angular speeds.

Fig. 5 shows comparative costs for a group of machines for a particular voltage and rating designed on this principle of constant diameter and on the principle of constant peripheral speed. Great care must, however, be taken in selecting the main dimensions for the fundamental design.

The impracticability of building continuous-current dynamos for outputs much above 500 k.w., without the use of some special commutating devices, led to the practice of coupling two dynamos on the same turbine for large sizes. Incidentally, this arrangement gave slightly higher dynamo efficiency at light loads, as only one machine of the pair would be in circuit, and some provision against breakdown of one machine was made by their being in duplicate. This, however, was expensive, and not the most desirable solution of the problem.

The difficulties reviewed above have led to a great amount of attention being given to commutation problems, and the consequent additions to knowledge of the phenomena of commutation have been very considerable. For high-speed dynamos where the reactance voltage per segment cannot be kept within its practicable limit by ordinary procedure in design, recourse has to be had to some form of compensatory winding on the armature or auxiliary magnetic poles placed between the main poles, with the object of reducing the voltage in the coil undergoing commutation either to zero or to a practicable value. Auxiliary windings on the armature were proposed in 1892 by Sayers,* the auxiliary coil between any two segments being so placed that it moves under a main pole, while the armature coil between those segments is undergoing commutation and has induced in it a voltage equal and opposite to the reactance voltage. These necessitate an amount of inactive copper on the armature and a somewhat complicated grouping of the armature windings. The more satisfactory solution is the use of auxiliary poles, and the wide application which these now obtain by nearly all makers speaks for their utility. The auxiliary poles carry a series winding which can be so proportioned that the auxiliary field in which the coil is moving at the time of commutation is just sufficient to neutralise the reactance voltage of the coil.

The calculation of the necessary flux entering the armature from the auxiliary pole is derived in the following way :—

Let $l =$ the length of embedded conductor lying within the region of the flux issuing from the pole, *i.e.*, the length of conductor which actually cuts the auxiliary field.

This length will be equal to the breadth of the pole shoe, parallel to the shaft b, multiplied by 1·1 to allow for fringing of the field at pole tips, and by 0·7, because, of the total length of a face conductor, only about 0·7 of it is "active" or "embedded" in armature iron, the remaining 0·3 being taken up by air ducts and core insulation. Hence, $l = 1{\cdot}1 \times 0{\cdot}7 \times b = 0{\cdot}77\, b$. If S = the peripheral speed of armature in cms. per second, and B the average density in the air-gap of the auxiliary pole in c.g.s. lines per sq. cm., then the rate of cutting of flux by one conductor is equal to—

$$\frac{B \times l \times S}{10^8}.$$

If we have t turns in the short-circuited coil, the electromotive force generated in this turn is equal to—

$$\frac{t \times 2 \times B.l.S}{10^8}.$$

This electromotive force must be sufficient to neutralise the reactance voltage.

If $v =$ the mean reactance voltage—

$$\left(= \frac{\text{Reactance voltage}}{\frac{\pi}{2}}\right).$$

* *Journal of Institution of Electrical Engineers*, vol. 22, p. 377.

Then we have—

$$v = \frac{2 . t . B . 1 . S}{10^8}.$$

Whence—

$$B = \frac{v \times 10^8}{2 t . l . S}.$$

which determines the requisite flux density at the pole face.

The length of the pole arc of the auxiliary pole is chosen such that during the whole period of commutation a coil shall be moving in the auxiliary field.

It is important that the coil shall be moving in a sufficient field at the moment when its commutator segments are leaving the brushes. The pole arc should cover as many slots as are carrying conductors simultaneously short-circuited by the brush, and it is safer to have a slightly larger pole arc than this to allow for any distortion of the auxiliary field, which may occur with varying load.

The total flux crossing the gap per auxiliary pole may now be deduced from the dimensions of the pole face. The total flux generated in the pole is this quantity multiplied by the leakage coefficient of the auxiliary circuit referred to above. The total ampere-turns required on the auxiliary pole are made up of a number equivalent to the magnetomotive force of the armature, and a number of ampere-turns sufficient to send the flux across the auxiliary air-gap and round the auxiliary magnetic circuit, *i.e.*, through the pole core and teeth immediately under the pole face. As this saturation component of the ampere-turns is relatively small compared with the armature reaction component, the total ampere-turns on the pole will not be much increased by saturating the pole core to a fairly high value, thus reducing the cross-section of pole to a minimum, and consequently the peripheral length of the winding, and obtaining a minimum weight of copper.

We see from the above that the commutation is not enhanced by high speeds, high outputs and high voltages. From this it would follow that commutating poles are more applicable the more either or all of these factors predominate, but for machines of any particular voltage, output and speed, which have been designed on ordinary lines and have shown satisfactory commutation constants, there should be no reason for applying commutating poles, which would then constitute a needless expense. If by using auxiliary poles the commutation trouble is eliminated, the sparking limit of output ceases to exist, and the output now becomes limited only by thermal considerations. Auxiliary poles have been of recent years applied by several makers to all kinds and sizes of machines, especially to reversing and variable-speed motors, but in some cases indiscriminately and needlessly. This led to greater attention to ventilation to increase the thermal limit of output (apart from turbine speed machines) with the outcome of several forms of ventilated field coils and more systematically ventilated armatures, together with an increase in rating all round.

A recent development in the matter of brushes is the appearance of a graded carbon brush* having low resistance at the leading tip, *i.e.*, the tip to which a commutator segment approaches, and graded off to high resistance at the trailing tip at which the short-circuited coil is broken. The effect of this is to gradually introduce resistance into the short-circuited coil during commutation. While the resistance across the brush is high and graded, the mean axial resistance, *i.e.*, to the main current, can be of the same value as an ordinary carbon brush, with consequently no greater voltage drop. These brushes are stated to stand overload tests without brush shift or sparking.

The most common alternative to auxiliary poles is a compensating field winding placed between the main poles, and which has precisely the same action as an auxiliary pole. The A.E.G. of Berlin employ the Deri winding for their continuous-current machines. In these machines the external field is similar to the stator of an induction motor with the field coils distributed in slots. The compensating coils are in series with the armature, and are embedded in slots round a large tooth or reversing lug, located between the main field coils. Messrs. Parsons in their early continuous-current machines employed an automatic brush-shifting gear. The brush rocker was connected to a small piston, which was subjected to steam from behind the turbine poppet valve, the pressure of which was found to be proportional to the load. The arrangement may be adjusted so as automatically to give an amount of lead to the brushes in proportion to the load.

This has been abandoned in favour of a compensatory winding, designed by Messrs. Parsons and Stoney, which is distributed in slots in and between the pole faces completely around the periphery of the armature.

Seeing that by use of compensating poles or windings the commutation difficulty can be eliminated, the question arises as to whether carbon brushes cannot be dispensed with, as they no longer play an essential part in the commutation. There seems to be little reason why metal brushes should not be substituted for carbon; with metal brushes the contact resistance is about one-eighth of that of carbon brushes, and the permissible current density 150 to 300 amperes per square inch, as against 25 to 40 amperes per square inch without excessive heating at the contacts. This means that the brush contact area need be only some quarter to one-eighth of what it would be for carbon brushes, and a proportional reduction in the length or diameter of the commutator would result. As in high-speed machines the commutator assumes very large proportions compared with the armature, and the problem of centrifugal force of the segments is involved, the metal brush seems to offer advantages. This question has received considerable attention in the several papers and discussions on same relating to turbines and turbo-generators in the *Journal* of the Institution. In the paper by Messrs. Parsons, Stoney and Martin,† there occurs the following passage: "Carbon brush blocks cannot be used,

* Developed and made in England by the Morgan Crucible Company.

† Vol. 33, p. 808.

as at these speeds the brushes are apt to vibrate, and so diminish the intimacy of contact and cause heating and undue wear. The result is that it has been found best to form the brushes of wire, gauze or foil, preferably of brass, and these must be sufficiently flexible to maintain a good contact with the commutator over the whole section of the brush."

In the discussion on this paper, Mr. Sayers stated that metal brushes were operated quite satisfactorily on machines wound with his compensating winding. It was also stated that carbon brushes were quite practicable on turbines if the amount of subdivision of the brushes was great and each separate block mounted to have the smallest possible amount of inertia. W. J. London, in a paper on "Steam Turbines and Turbo-Generators,"* says: "It has been found that it is almost impossible to use carbon brushes on this type of generator, owing to the fact that the armature floats when running, thus causing the brushes to dance. Metal brushes must, therefore, always be used, and in consequence, unless satisfactory commutating poles or compensating windings are adopted, the position of the brushes must be altered to suit small variations in load."

The voltage drop and loss in the brushes is also considerably reduced by metal brushes, and an increase in efficiency from 1 to 2½ per cent. may result. This, however, may be offset by the extra loss in the compensating windings. The friction coefficient with metal brushes is also some two-thirds of carbon brushes.

Construction of High-Speed Continuous-Current Dynamos.

Frames and Yokes.—The general design of the frames does not differ from those for low-speed machines, as no influences dependent on the speed are involved in the stationary part of the machine. Care should be given to the strong attachment of the field poles to the yoke or the pole shoes to the poles, to avoid vibration. The same point holds for the auxiliary poles of machines using them. The auxiliary pole being of small cross section, there is only room for one bolt to hold it on to the yoke, which should be strong enough to hold it firm against vibration due to continued magnetic pulls on the pole. A good method would be to make the auxiliary pole of a single forging with a cylindrical tail ¾ inch or more in diameter, threaded and screwed into a hole in the yoke. The auxiliary poles should be set away from the centre of the yoke towards one end, as this arrangement allows more room for the series winding, which will not then come in the way of the main pole field coils. Some makers shift the auxiliary pole actually outside the region of the armature and use a long pole shoe projecting on to the armature. In the de Laval turbine, where the speed is reduced through a gearing, two dynamos are generally employed with parallel shafts. This arrangement gives rise to a double yoke for the two armatures which follows the lines of Fig. 6. Exception to general practice is taken by the A.E.G. of Berlin and Messrs. Brown-Boveri

* *Journal of Institution of Electrical Engineers*, vol. 35, p. 185.

& Co., who are constructing field structures for continuous-current dynamos on the lines of the stator of an ordinary induction motor.

Armatures.—The construction of armatures for high speeds is essentially a mechanical problem, by reason of the high mechanical stresses set up by centrifugal forces in the rotating parts, the winding and insulation. The safe limit for peripheral speed is 20,000 ft. per minute (100 metres per second). At this speed the surface stress for materials of specific weight equal to that of steel or wrought iron is approximately

$$F = \frac{V^2}{10}$$

where V = peripheral speed in feet per second. Hence for a speed of 20,000 ft. per minute the stress is 11,000 lbs. per square inch, irrespective of the diameter, which is as high as it is desirable to go. In fact, we rarely find the armature peripheral speed exceeding 15,000 ft. per minute, 10,000 to 12,500 being more usually employed. This value sets a limit on the diameter of the armature. The diameter of

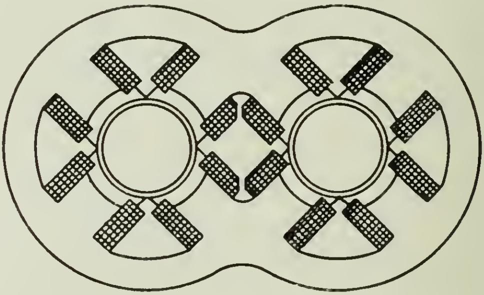


FIG. 6.

shaft stiff enough to be consistent with the long span between bearings reaches a considerable proportion of the armature diameter. The magnetic circuit and possibilities of ventilation are closely dependent upon the space occupied by the shaft and its relative diameter to the external diameter. The two latter being limited in opposite directions does not facilitate the general problem. The small diameter usually permits of the armature stampings being mounted directly on the shaft, which is advantageous from the mechanical standpoint, dispensing with a cast spider. The stampings should be punched with tunnel holes to assist ventilation. The slots would preferably be completely closed tunnels to retain effectively the conductors against their centrifugal force. This is not in accordance with other requirements, as the inductance of the windings is increased, and former winding is not possible. Many makers use a half-closed slot with a clamping strip in the mouth ; this, or in some cases a totally open slot with a dove-tail wedge, should be sufficient. The clamping strip transfers the centrifugal force of the conductors to the teeth, which

must be of sufficient cross section at their roots to withstand this and their own centrifugal force.

In the early machines the armature was bound over throughout its length with steel binding wire; this is impracticable if there are a large number of core ducts, and is, perhaps, none too reliable. The end connections of the armature winding call for special provision. The two prevalent methods are to encircle them with steel binding wire, as shown in Fig. 7, or with cylindrical metal end covers, as shown in Figs. 8 and 9.* Fig. 9 is used by the Lahmeyer Electrical Company. Fig. 8 is a method of the Austrian Union Company, in which the diameter and consequent centrifugal force of the end windings is reduced. The material of the end bells is phosphor bronze, manganese bronze (of elastic limit 30,000 lbs. per square inch),

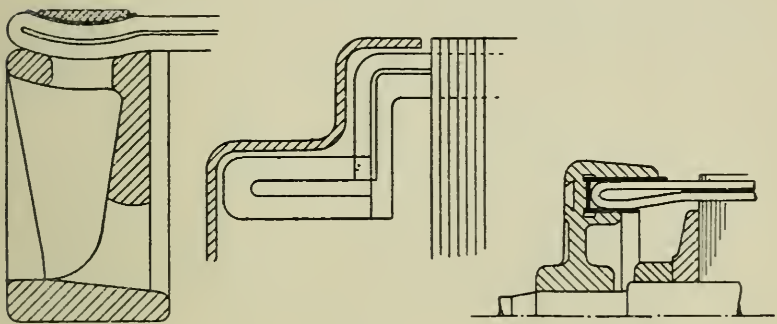


FIG. 7. FIG. 8. FIG. 9.

or nickel steel (elastic limit 50,000 lbs. per square inch). The stress in the end bell is—

$$F = \frac{(C_1 + C_2)}{\pi \times 2a},$$

where C_1 and C_2 are the total radial centrifugal force of the windings and of the end bell respectively, and a = the cross section of the end bell. (The centrifugal force of a mass M lbs. rotating at N revolutions per minute at a mean radius R inches is $C = 0{\cdot}0000284\, M\, R\, N^2$, whence C_1 and C_2).

Commutators.—The ordinary commutator construction for commutator peripheral speeds not exceeding 3,000 ft. per minute fails to be adequate when the speed runs up as high as 7,000 to 9,000 ft. per minute, as is the case with turbine speed dynamos. If the ordinary dove-tail clamp rings at each end of the commutator were used, the centrifugal forces on the long segments would tend to bulging outward and to high bars. Hence the segments need some retaining member at the middle of their length. In the first Parsons machine the

* See also *Journal of Institution of Electrical Engineers*, vol. 35, p. 183. London on "Mechanical Construction of Steam Turbines," Fig. 12,

commutator was subdivided longitudinally by cutting the segments into several shorter lengths with dove-tail holding rings between each. A drawing of Parsons's original armature on this plan is to be found in the *Journal of Institution of Electrical Engineers*, vol. 35, p. 181, Fig. 11. This construction would be expensive and not too satisfactory, and is not now in use.

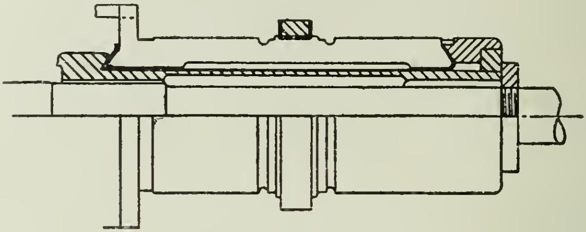


Fig. 10.

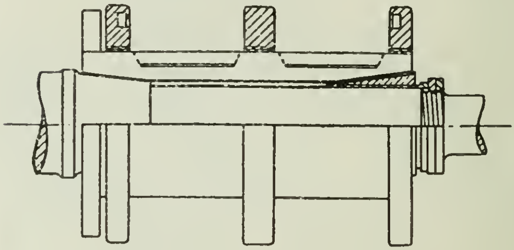


Fig. 11.

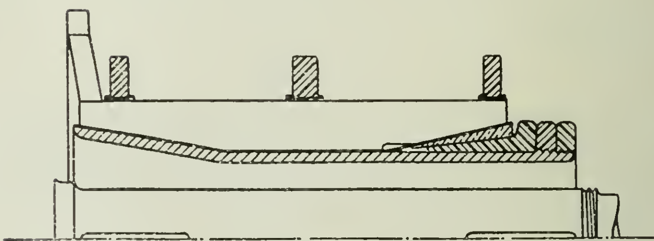


Fig. 12.

Fig. 10 illustrates a construction of the Union Company, where the commutator is built upon a sleeve with V clamp rings at the ends and a steel ring shrunk on at the middle of the length to take up the bending moment on the commutator bars.

Fig. 11 is typical of common practice for high speeds, the designs of most of the leading manufacturers following on these lines. The segments and insulation are assembled and the steel rings shrunk on over mica layers, and the whole machined inside and out ; the finished

commutator beds against a taper on the shaft being held by a taper collar and screw collar at its other end, as shown in Fig. 11. The stress in the rings is—

$$F = \frac{C_1 + C_2}{\pi \times 2 s},$$

where C_1 and C_2 are the total radial centrifugal force of the commutator segments and the rings (by their own weight) respectively. Allowing a safe working stress for F, we arrive at s, which is the total cross section of all the rings. The distance between the rings is determined by the bending strain on the segment.

Let a = the distance between rings.
d = depth of segment radially.
b = breadth of segment.
C = centrifugal force of that portion of a single segment which lies between two shrinking rings.

Then the bending strain on the segment is—

$$f = \frac{C \times a}{\frac{4}{3} s h^2}.$$

This should not exceed 15,000 lbs. per square inch for copper.

Fig. 12 shows a similar commutator built upon a sleeve, which permits of ventilating the interior of the commutator.

Fig. 13 is a type of segment used by the Brush Company as a further provision against centrifugal forces. The segments can be drawn to the section shown, and lock with one another when assembled.

Fig. 14 shows another similar type due to J. Burke.

Fig. 15 is a double ventilated commutator of Siemens Bros., where the segments are cut into two short lengths, each retained by V rings.

In the earlier machines Parsons used a commutator with surface corrugated with circumferential grooves, in order to increase the brush contact area and reduce the length of commutator. Some of these machines are still running. The brushes consist of bundles of wire whose flexibility admits of contact being made in the grooves turned on the commutator face.

Before leaving continuous-current dynamos, reference should be made to the homopolar or acyclic type of dynamo, which has called for attention in connection with the problem of building large continuous-current units for high speeds. This type of generator is so arranged that the flux crosses the air-gap at all points in the same direction, and consequently the E.M.F.'s induced in the conductors do not reverse during the revolution, and hence the commutator can be dispensed with, which greatly facilitates the problem.

The acyclic generator is as yet in a developmental stage, and should be dealt with in a separate paper. It is being well developed by the General Electric Company of America, who have recently built a

300-k.w. 500-volt continuous-current machine* for direct driving with a Curtis turbine at 2,000 r.p.m.

Alternators.—The same remarks as to temperature rise and speed apply here as in the case of continuous-current dynamos, namely, that within the practicable range of speeds the heating limit can be provided for without increase in dimensions. We shall now look briefly into the subject of pressure regulation, with a view to seeing how the factors which concern the regulation are affected by the speed.

Voltage Regulation.—The regulation of an alternator is usually specified as the percentage by which the terminal voltage rises when the load is decreased from full load to zero,† without changing the speed or field excitation. This is generally specified for full load at

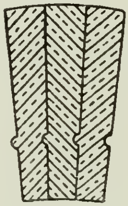


FIG. 13.

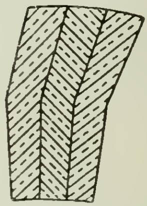


FIG. 14.

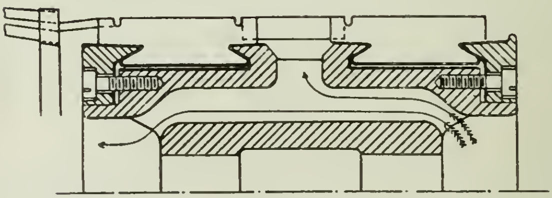


FIG. 15.

unity power factor (usually 4 per cent. to 7 per cent.), and for full load at power factor = 0·8 (usually 15 per cent. to 22 per cent.).‡ It is sometimes customary to specify the excitation regulation also, which is the increase in field current from no load to full load as a percentage of the field current at no load, to maintain full terminal voltage.

Many methods more or less accurate have been suggested for calculating the regulation, the prime object being to estimate the amount of armature demagnetisation which takes place on the field on non-inductive and inductive loads. The demagnetising component

* See *Proceedings* of the American Institution of Electrical Engineers, vol. 24, p. 1, 1905. Noggerath on "Acyclic Dynamos."

† This is the most common specification, though an alternative is to specify the voltage *drop* when full load is suddenly switched on. See Taylor on "Armature Reactions in Alternators" (*Journal of Institution of Electrical Engineers*, vol. 33, p. 1144).

‡ The Engineering Standards Committee recommend 6 per cent. on full non-inductive load and 20 per cent. on inductive load of p.f. = 0·8 as maximum values.

of the armature ampere-turns for a load of A amperes at power factor $= \cos\phi$ is

$$D = K \times B \times A T \times \sin\theta,$$

where T = the total number of turns per pole for all the phases.

B = the breadth coefficient of the winding. (For ordinary 3-phase windings, B = 0·95.)

θ is the internal phase angle between the current and voltage.

$$\theta = \phi + a + \beta,$$

where a is the phase angle due to the armature inductance, and β the angle due to distortion of the flux.*

K = a constant depending on the ratio of pole arc to pole pitch, and lies between 0·75 to 0·8.

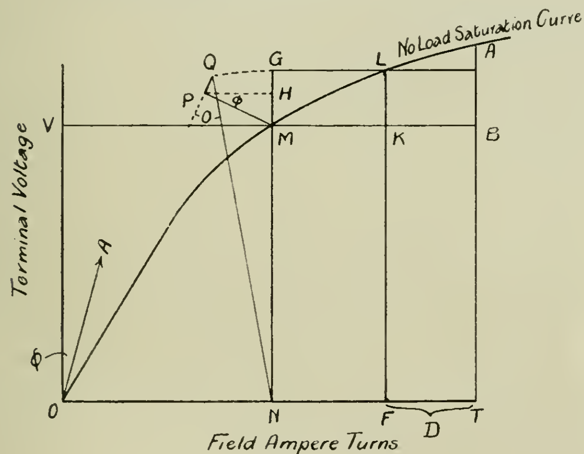


FIG. 16.

A number of ampere-turns must be added to the field ampere-turns for full terminal voltage at no load, equivalent to the armature demagnetisation D, in order to maintain full terminal voltage on load, and in addition to this a further number of ampere-turns must be added sufficient to produce in the armature a voltage equal to the resistance drop on the armature and the component of the inductive drop which is in phase with the terminal voltage.

The resistance drop is = A R, where A = amperes per phase and R = resistance of one phase.

The inductive drop is $A \times 2\pi n l$, where n = frequency and l = self-inductance of armature per phase. The component of this drop in phase with the terminal voltage is $A \times 2\pi n l \times \sin\phi$. This will be seen on reference to Fig. 16.

* For method of calculating a and β and for full description of this method, see a paper by Hobart and Punga entitled "A Contribution to the Theory of the Regulation of Alternators" (*Journal of American Institution of Electrical Engineers*).

O N = field ampere-turns at no load for full terminal voltage O V, O A = current lagging angle ϕ on the terminal voltage O V. M P is the inductive drop which is in quadrature with O A, and H M is its component in phase with O V; evidently H M = M P sin ϕ, becoming zero when $\phi = 0°$. P Q = resistance drop in phase with O A. Then adding vectorially, the internal armature voltage for terminal voltage O V (= M N) is Q N lagging an angle θ ($= \phi + \alpha + \beta$) on the current O A.

Making N Q = N G, then M G (= L K) is the extra voltage required which needs a number of ampere-turns equal to M K (= N F) on the field. Adding on F T = D, the armature demagnetisation, we get the total field ampere-turns O T (= V B) required for full terminal voltage at full load (O A amperes) of power factor cos ϕ, and B is a point on the full load saturation curve for power factor = cos ϕ.

Supposing now this load to be suddenly switched off, the armature demagnetisation and voltage drop disappears, and the voltage rises to T A, A being the point on the no load saturation curve corresponding to field excitation O T, and A B is the pressure rise. A B expressed as a percentage of O V (= T B) is the regulation at full load of power factor = cos ϕ. The increase in excitation B M as a percentage of the no load excitation O N (= V M) is the excitation regulation.

A study of the quantities involved in Fig. 16 will show what factors must be attended to in order to effect a diminution in A B, or to keep the regulation within the limits specified above. This can be done by dropping the point A downwards, or by shifting point B inwards. The first method means reducing the voltage rise by virtually bending the no load saturation curve over, *i.e.*, by working the iron of the magnetic circuit very near its saturation limits. This procedure is advantageous in that it minimises the cross-section of the magnetic paths, and consequently the total weight of iron in the machine; also by saturating the pole cores very high, the mean length of one turn of the field winding is minimised, and consequently the weight of the field copper. It is dangerous, however, in case the material (especially if castings) of the magnets turns out to be of inferior quality, and also should the machine be called upon to run at a voltage greater to any extent than the normal voltage, there will be difficulty, and perhaps impossibility, of getting sufficient flux through the machine for the high voltage, no matter how much the excitation is increased. The excitation regulation is also very great.

With due regard to these points, it is best practice to keep within reasonable flux densities, for which the following are not uncommon practice as maximum values :—

	Lines per Sq. Inch.	Lines per Sq. cm.
Pole cores of wrought iron ...	100,000	15,500
Pole cores of cast iron	60,000	9,500
Teeth, best wrought iron	130,000	20,000

The density in armature is chosen with respect to the core loss, and usually lies between 40,000 and 60,000 lines per sq. inch, according to the frequency.

The second method of keeping the regulation low is by reducing the armature demagnetisation B K (Fig. 16) and the ampere-turns required for the ohmic drop, M K, or by increasing the no load excitation, V M, greater in proportion to M B.

To reduce B M, the demagnetisation and ohmic drop excitation, entails a reduction in the number of stator turns, *i.e.*, the use of a less strongly reactive armature. This necessitates a proportional increase in flux per pole to give the voltage, and a corresponding increase in the iron dimensions to carry this flux at inexcessive densities.

The dimensions thus increased may be larger than are required to give sufficient radiating surface for a normal temperature rise, and thus in the interests of economy of material it is desirable to work with strong armatures of many turns, and air-gap dimensions (diameter and core length) as small as will give sufficient radiating surface for the armature. The only alternative is now to set out with a larger no load excitation, V M. This is made up of two components, the ampere-turns for air-gap, V C, and the ampere-turns for the iron of the magnetic circuit, C M (Fig. 17). Of these, C M will already be of maximum practicable value if the iron is saturated up to its desirable limits, so there remains to increase V C by increasing the length of air-gap. This should be done up to such a value for V C that the regulation comes within its limits.

With modern iron-clad alternators, the short-circuit current for full voltage field excitation and speed is from two to four times the full load armature current for machines of normal regulating properties. This affords a way of determining a preliminary value for the length of air-gap, which can be adjusted to give the required regulation.

In Fig. 17, O E is the short-circuit curve, where O S is the short-circuit current at normal excitation, O N.

Assuming as a preliminary figure that this short-circuit current is three times the full load current, we know that the armature demagnetisation is three times the full load armature reactive ampere-turns per pole for all phases. We can calculate the latter from the current and turns per phase, and thus the armature ampere-turns on short-circuit, which must be equal to the no load field ampere-turns, O N, as they are counterbalanced by them. The ampere-turns for air-gap are usually some 80 per cent. of the total ampere-turns, and thus we have $VC = 0{\cdot}8 \times ON$ (Fig. 17). Knowing the air-gap density, Bg, from the flux and pole face area, we have—

$$lg = \frac{\text{Ampere-turns for gap}}{0{\cdot}8\ Bg}$$

$$= \frac{0{\cdot}8 \times \text{armature A T's on short-circuit}}{0{\cdot}8\ Bg} = \frac{\text{Armature A T's}}{Bg}$$

which gives our preliminary value for lg, the length of air-gap.

For example, take a 1,000-k.w., 5,000-volt, 3-phase Y alternator.

$$\text{Full load current} = \frac{1{,}000 \times 1{,}000}{3 \times 5{,}000} \times \sqrt{3}$$

$$= 115 \text{ amperes per phase.}$$

Supposing there are 160 turns per phase and eight poles, then the armature ampere-turns per pole per phase at full load are

$$\frac{160}{8} \times 115 = 2{,}300.$$

The resultant of three phases is

$$0{\cdot}71 \times 3 \times 2{,}300 = 4{,}800 \text{ (see p. 325)}.$$

If now we take the short-circuit current three times the full load current, the armature demagnetisation on short-circuit is $3 \times 4{,}800 = 14{,}400$ ampere-turns. Supposing the pole face density comes out to 10,000 lines per sq. cm., then

$$lg = \frac{14{,}400}{10{,}000} = 1{\cdot}44 \text{ cms.}$$

which may be taken as a basis for more detailed calculations.

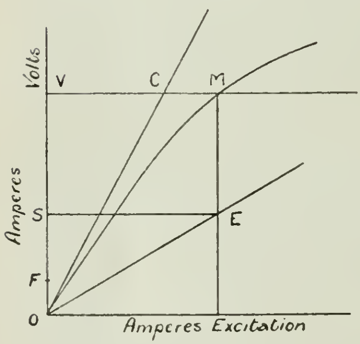


FIG. 17.

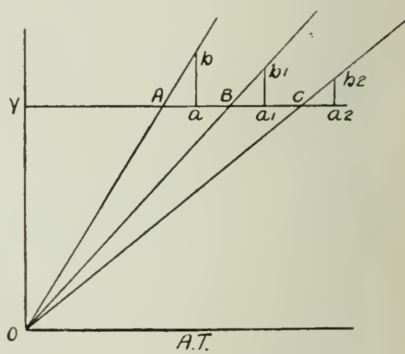


FIG. 18.

If the magnetic circuit is not saturated, the regulation can be considerably improved by increasing the air-gap, as will be seen from Fig. 18. Since the iron saturation component is small, we may treat the saturation curve as a straight line.

1. Suppose with a certain length of gap the excitation is V A for full voltage, and A a is the armature demagnetisation. Then the regulation is $\frac{a\,b}{\mathrm{O\,V}}$, which equals $\frac{\mathrm{A}\,a}{\mathrm{V}\,a}$.

2. Now if the length of gap is increased by 50 per cent., then the excitation is $\mathrm{V\,B} = 1{\cdot}5 \times \mathrm{V\,A}$. For the same armature we have $\mathrm{A}\,a = \mathrm{B}\,a^1$, and the regulation is $\frac{a^1\,b^1}{\mathrm{O\,V}} = \frac{\mathrm{B}\,a^1}{\mathrm{V\,B}}$.

This equals $\frac{\mathrm{A}\,a}{1{\cdot}5 \times \mathrm{V\,A}}$, which is 33 per cent. less than in the first case.

3. If now the gap is increased by 100 per cent. on its original

value, then $VC = 2\,VA$, and for same demagnetising, $CA_2 = Aa$, the regulation is

$$\frac{a_2 b_2}{OV} = \frac{C a_2}{VC} = \frac{Aa}{2\,VA}$$

which is one-half what it is in Case 1.

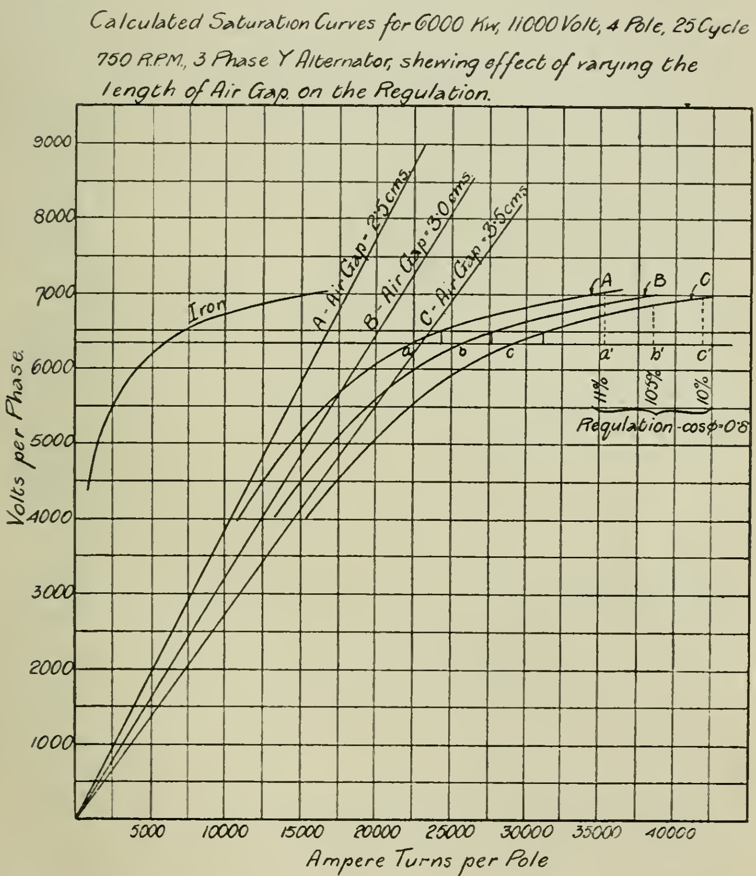


FIG. 19.

The regulation is, for the three cases, proportional to the figures 100, 66, and 50 for air-gaps of length proportional to 1, 1·5 and 2, and the product of regulation × length of gap is a constant. Hence, if there were no ampere-turns expended on the iron in the circuit, the regulation would be inversely as the length of air-gap. If, however, the iron is saturated up as high as possible, the machine saturation curve is similar to one of those shown in Fig. 19.

These curves represent the calculations for a high-speed alternator, with the iron highly saturated and the air-gap made 2·5, 3·0, and 3·5 cms. in turn, as designated by the letters A, B and C in Fig. 21. Making $aa^1 = bb^1 = cc^1 =$ the extra excitation required for full load at $\cos \phi = 0{\cdot}8$, it appears that the regulation is only improved from 11 per cent. in Case A to 10·5 per cent. in Case B, and 10 per cent. in Case C, for increases in air-gap of 20 per cent. and 40 per cent.; the increase in the total amount of field copper is somewhat less than these percentages, being proportional to the total ampere-turns in each case in Fig. 19, but they are relatively of the same order. The regulation at unity power factor is unchanged to any appreciable extent.

From these considerations it would be good practice, from the standpoint of economy of material and from the standpoint of protection of the machine on short circuit, to work with a rather strongly reactive armature, and moderately high flux densities with an air-gap as short as will give normal regulation.

Coming now to consider how the voltage regulation is concerned with high speeds, we have to consider the armature demagnetising ampere-turns and their relative magnitude compared with the field ampere-turns. The number of poles is small, being fixed by the speed and frequency, and thus the pole pitch and length of pole arc are large, the diameter being as large as is permitted by the limiting value of the peripheral speed. Hence the magnetic flux per pole is large;* in fact, as large as can be got through the machine at inexcessive flux densities (the largest dimensions allowable for the pole core being determined by laying out the armature diameter and length, which dimensions are cut as small as is consistent with the heating limit).

Thus, comparing with low-speed machines, the number of armature turns per phase requisite to give the specified voltage are relatively small, and the armature is not strongly reactive. This being so, the armature is of lower inductance, which is also contributed to by the windings being very distributed; the number of slots per pole per phase is large in turbo-alternators, ranging from four to nine, because of the few poles and the desirability of keeping reasonable values for width of armature, slots, and teeth. Hence the internal angle of lag of the current, due to armature inductance, is small. In cases where the field winding is distributed in slots this angle is further reduced, as the distorting effect of the armature ampere-turns on the flux is not so marked.

From this it would seem that the use of high speeds effects improvement on the regulating properties, but the influences referred to above do not of themselves result in a machine with abnormally low regulation. It has been stated that on some of the Parsons turbo-alternators pressure drops of only 0·5 per cent. at full load have been obtained. This is presumably on non-inductive load, and such a very low figure can only be obtained by a very large expenditure of field copper. As such fine regulation is not called for in ordinary cases, it is better practice to economise field copper and also assist in pro-

* The flux per pol in large machines runs up as high as 50 megalines.

tecting the machine on short-circuit, by working to a normal regulation of 5 or 6 per cent. This point is borne out by examination of any recently built turbo-alternators. However, even for normal regulation the air-gaps of turbo-alternators are necessarily long. As an outside instance, the air-gap of the 5,500-k.w. 1,000-r.p.m. Westinghouse turbo-alternators at Chelsea is $3\frac{1}{4}$ ins. These long air-gaps are due to the large number of ampere-turns on the armature per pole, by reason of the small number of poles.

It was stated at a previous point that normal machines give a short-circuit current of about three times the full load current—that is, the normal no load field excitation is three times the full load armature demagnetisation, and hence the field ampere-turns per pole are very

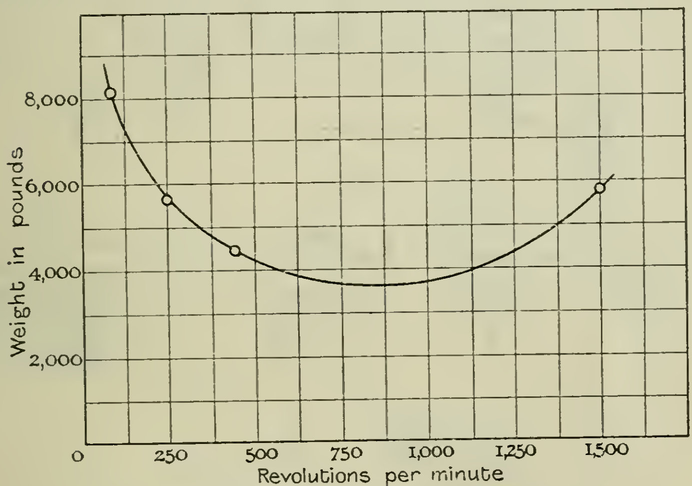


FIG. 20.—Behrend's curve showing comparative weights of 1,000-k.w. 3-phase, 25-cycle generators at different speeds.

large. In fact, the ampere-turns per field spool in high-speed alternators with few poles reach values up to 40,000 in large outputs, as against figures more of the order of 5,000 in low-speed fly-wheel alternators. The necessary ampere-turns can be expended on the iron of the magnetic circuit by saturating high, or on the air-gap by working with a long gap. We have discussed above the relative merits of high saturation and long air-gaps; even with high flux densities long air-gaps become necessary to take up the large number of field ampere-turns. Thus from considerations of temperature rise and regulation it appears that high speeds are not unfavourable, and as the commutation limit is not involved, it would seem that a continual increase in rated speed would result in a corresponding diminution in weight. Theoretically this should be so, but in practice a contrary and very interesting result has been arrived at by Behrend,* for a number

* *Electrical Review*, New York, vol. 45, pp. 375–378 (1904).

of 1,000-k.w. generators at different speeds. Behrend's curve is shown in Fig. 20, which indicates that the weight of a 1,000-k.w. 3-phase 25-cycle alternator reaches a minimum value for a speed of 900 r.p.m., and the weight is as much at 1,500 r.p.m. as at 250 r.p.m. This result is for several machines designed and built by the same firm, and the increase in weight at higher speeds is to be attributed to more material being required to meet the mechanical requirements at high speeds. For this case the speed for minimum weight is considerably lower than the speeds of steam turbines of corresponding output (see Fig. 1), but the latter are much more favourable to alternators than to continuous-current generators.

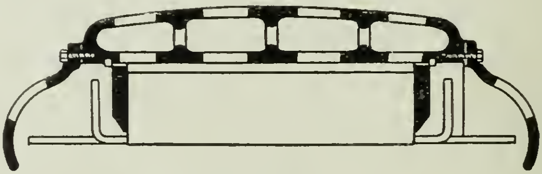


FIG. 21.

FIG. 22.

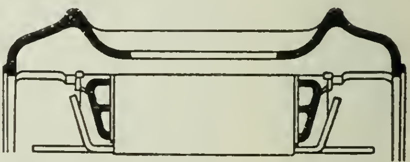


FIG. 23.

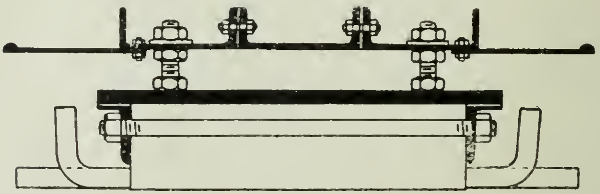


FIG. 24.

Construction of High-speed Alternators.—Alternators are mostly of the rotating field type, as this type offers many advantages over the rotating armature type. The latter is employed only for comparatively small machines, one advantage here being the smaller core loss in the armature owing to decreased weight. In large outputs the collection of heavy currents at high voltage becomes objectionable, and the revolving field type of alternator is almost always used. The remarks already made on rotating armatures for continuous-current machines apply equally to alternator revolving armatures, except that the latter are relieved of the commutator problem.

Stator Frames.—The frames for alternator armatures at high speeds

do not present such problems as yokes for low-speed fly-wheel alternators. The latter have to constitute a rigid structure in themselves and support the armature without any deflection, and their design for the huge diameters involved in slow-speed work is quite a structural problem.

In the case of alternators at turbine speeds, the proportions are much different, and we rarely find an air-gap diameter much greater than 6 ft., even in a 6,000-k.w. machine, because of the peripheral speed limit. Thus the largest overall diameter of frame seldom exceeds 12 ft., the overall length being large, up to about 8 ft. in largest sizes. Such a frame has very different proportions from a flywheel type, and the precautions for rigidity are not nearly so great. The stiffness is contributed to considerably by the rigidity of the armature core body; the radial depth of the stampings is usually very great, having a value from 0·3 to 0·4 of the pole pitch, which latter is itself

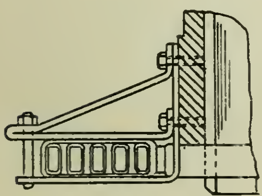


FIG. 25.

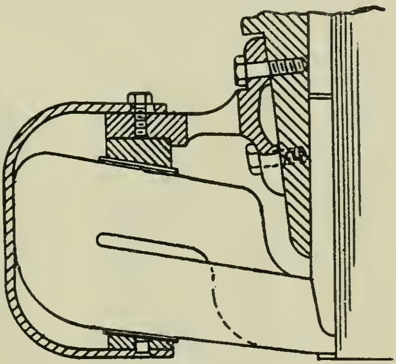


FIG. 26.

large, so that the friction between the plates adds to the rigidity of the whole structure.

Several types of housing suitable for long core lengths are shown in Figs. 21 to 24. Fig. 21, the Westinghouse Company's construction, is a well-ventilated yoke of the box type, made in two similar halves bolted together at a horizontal division. Fig. 22 is a similar construction used by the British Thomson-Houston Company, and the General Electric Company of U.S.A. for their Curtis turbine sets. In these machines, which have vertical shafts, the yoke is not split.

Fig. 23 is a rigid form of yoke strengthened by a number of longitudinal ribs.

Fig. 24 shows a new type of frame built up of rolled plate and angle iron. The laminated iron is built up separately, and is then placed in the casing and held by radial spacing bolts.

Armature Windings.—Armature windings for stationary armatures are mostly carried out as coil windings. The large pole pitches render bar windings or barrel windings impracticable. By reason of the few

poles and the large number of slots per coil, the coils project a long way out at the ends of the core. These ends are subjected to magnetic pulls due to the stray field which may distort them, and against this it is common to strap the coils on to the stator frame with straps of non-magnetic material, resting on wooden blocks in some cases (Figs. 25 and 26).

Rotating Field Structures.—A great deal of attention has been given to the constructional problem of rotating fields for alternators at high speeds, and several very satisfactory schemes have been evolved by the various firms engaged. There are many different possibilities of construction, depending upon the individual requirements of each case, and we shall here deal with representative types at present employed.

The material used depends to some extent upon the style of construction, and speaking generally, the properties of the material as to homogeneity, durability, elasticity, and tensile strength are all-important factors. Castings should be avoided except in special cases, or if the

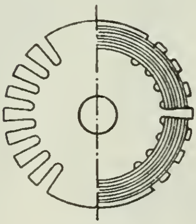


FIG. 27.

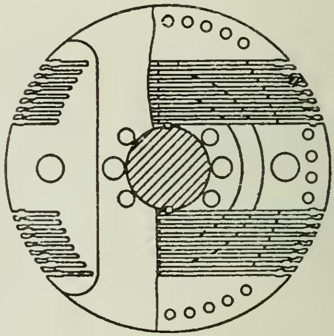


FIG. 28.

peripheral speed is low. Cast steel is employable, but there is danger from blow-holes. The materials therefore used are varieties of wrought iron or forged steel of best quality. The large rotors of the 5,500-k.w. generators at the Chelsea station of the Underground Electric Railways are built of "Whitworth Fluid Pressed Steel."

There are two general types of rotating field in use, the one having definite pole pieces with bobbins and coil windings, the other consisting of a smooth core with the windings arranged accordingly in slots. The smooth-drum type was employed by C. E. L. Brown at the outset, and at the present time Messrs. Brown Boveri & Co. use this type in all their machines, from 100 k.w. at 3,000 r.p.m. to 6,000 k.w. at 750 r.p.m. Fig. 27 illustrates one form of Brown's construction as set forth in German Patent No. 138,253. The patent claim is the subdividing of the field winding into a number of slots with a view to distributing the centrifugal force of the winding, the whole of the field iron being thereby brought into close proximity with the armature face, and the space between the usual salient pole pieces being utilised. It might

be thought that such a scheme and the presence of the winding teeth would lead to stray fields and leakage, but this has not proved the case. Several varieties of construction are provided for by the patent, the differences being in the nature of the slot arrangement. In one case, the slots are milled perpendicular to the axis of the magnet poles; in Fig. 27 the slots are radial; they may also have their depth parallel

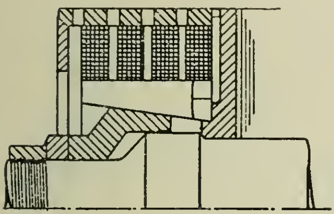


FIG. 29.

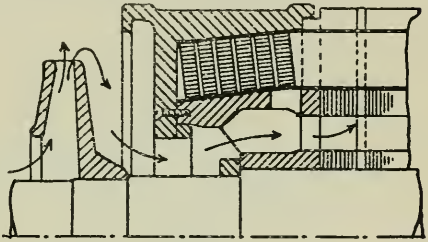


FIG. 30.

with the magnet axis, or may consist of a series of tunnel slots, which are more suitable for cable windings. Fig. 27 shows a 2-pole system, but the structures are easily extended to multipolars, where they should be more applicable owing to the smaller lengths of the unembedded parts of the field winding. The open slots are always closed by wedges of a special non-magnetic bronze, sometimes with an insulating wedge, according to the exciter voltage. For large sizes, Messrs. Brown Boveri & Co. use laminated sheet iron assembled on a steel shaft, the general design being the same as where the rotor is made of a solid piece of steel. The end parts of the winding are held in place by bronze cylinders similar to those employed in continuous-current armatures. The inside of these covers is well insulated, and the windings press on when running by their own centrifugal force. A series of radial wings on the covers provide an air-draught for cooling. The exciting current is led in at two hard cast-iron slip-rings, which are placed one at each end of the rotor.

A similar smooth-drum construction is used by the Westinghouse Company for bi-polars. This is illustrated in Fig. 28, and is similar to Brown's construction (Fig. 27). The end connections of the field windings are embedded in milled slots, dispensing with the end covers of Brown's structure. The winding slots are here milled in all round the rotor body at right angles to the pole axis, and the windings secured by strong key pieces in the mouths of the slots.

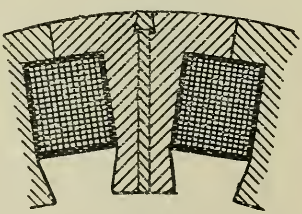


FIG. 31.

In large sizes the Westinghouse Company use a structure with definite pole pieces, the winding being embedded in milled slots similar to the above (see Fig. 38).

Figs. 29 and 30 illustrate methods of holding the end portions of the field coils employed by the Bullock Company of U.S.A. and the Oerlikon Company.

Fig. 31 is the method of the A.E.G. of Berlin, who use a smooth core with dove-tail held projections pressed against the coils and securing them by a thin wedge strip as shown.

The constructions already described have the poles and yokes in

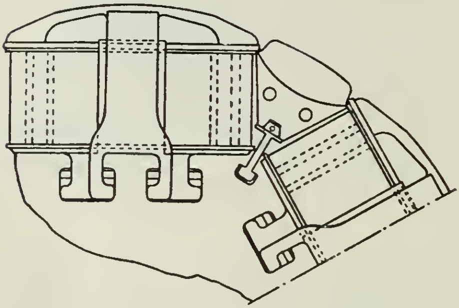


Fig. 32.

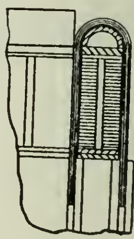


Fig. 33.

one piece with the field winding subdivided into slots and its centrifugal force distributed over a number of projecting ribs or teeth. Other possibilities already in use may have a solid hub with detachable pole pieces, or a solid hub and poles in one with detachable pole shoes. In these cases the winding is carried out on a bobbin slipped on the poles in the ordinary way, but special arrangements have to be made to

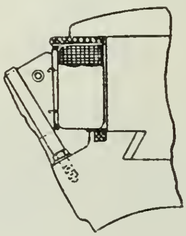


Fig. 34.

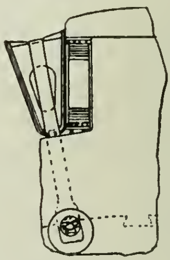


Fig. 35.

take up the large centrifugal force of the concentrated masses of copper. We shall deal later on with the stresses in various parts of the rotor, and meanwhile will review some constructions of this nature.

Figs. 32 and 33 illustrate the rotor construction of the British Thomson-Houston Company, the General Electric Company of U.S.A., and the Union E.G. of Berlin. Here there is a laminated hub with axial slots, into which projections on the pole pieces fit, being secured by square wedges. The field coils are held by angle brackets

between the poles, the end portions of the coils being secured by metal straps, C C, held by the wedges which secure the pole pieces.

Other methods of attaching these brackets are shown in Figs. 34 and 35. If the centrifugal force of the field windings is too great to be sustained by the pole shoe, the method shown in Fig. 37 will alleviate this. Here the coil is subdivided into three parts, the centri-

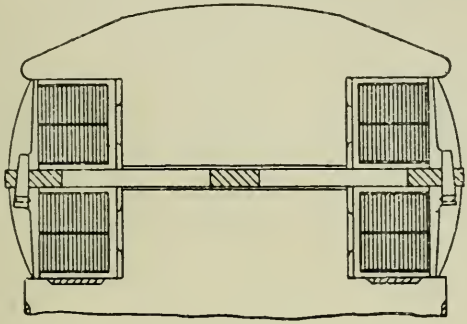


FIG. 36.

fugal force of each of which is transmitted to the pole body by means of a ring or pin sunk into a channel in the pole body.

Fig. 39, *a* to *k*, illustrates a variety of methods of attaching pole shoes and pole cores, suitable for high speeds; *a*, *b* and *c* are more applicable to moderate speeds where the diameter is sufficiently large to admit of a hub with a rim through which bolts can pass to secure

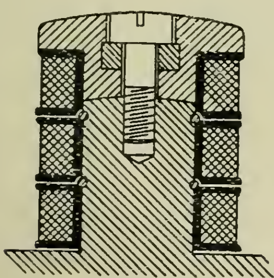


FIG. 37.

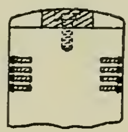


FIG. 38.

the poles; *d* to *k* are adaptable to hubs fitting direct on the shaft, being either solid, laminated, or built up of thick plates; *e* is a common method—the root may consist of a single dove-tail, as shown, or may be divided into two if the stresses are too great (see p. 339); *f* is suitable for laminated poles and hubs, the alternate stampings being staggered and secured by parallel wedges; *g* is for laminated poles and hubs, and has already been referred to under the British Thomson-

Houston Company's construction; *h* is a type which is built of thick plate, the hub plates being in form of a cross and the pole shoe pieces shaped as shown—alternate plates are staggered and secured by bars passing through the pole face; *i* and *j* are constructions with solid poles and laminated shoes let into grooves in the pole face. In *i* the grooves are milled and in *j* turned concentric with the pole face; *k* represents Parsons's method of attaching pole shoes.

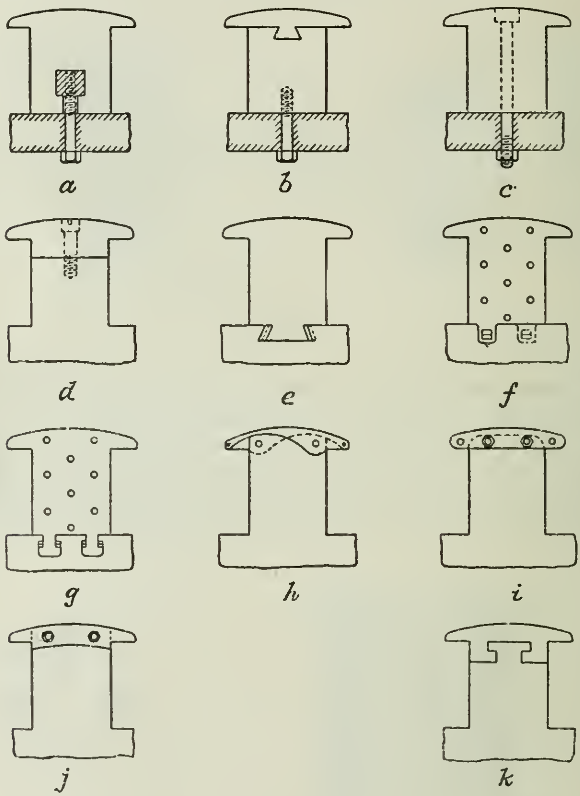


Fig. 39.

All of the above methods are very serviceable, and each one possesses advantages peculiar to itself which make it more applicable to certain cases. Some advantages claimed for the smooth-drum construction are a diminishing of the losses by air friction and more security as to noiseless running. The first of these is undoubtedly true, but on the other hand, with a continuous drum revolving within and close to the stator, the ventilating properties are not so good as the definite-pole construction with space between the poles. On the second point, the smooth construction has the advantage that the sudden variations in the

section of the currents of air caused by projections or irregularities in the shape of the rotating element augment the hum associated with high-speed machines. From this standpoint, the rotor should be designed to present as smooth surfaces as possible to the air. The definite-pole construction is employed by several makers in large sizes without experiencing trouble in this direction. In large rotors the solid construction is preferable to a built-up structure on the score of simplicity and safety, and also it presents less liability to balancing troubles. The question of balancing is, of course, of the utmost importance. The component parts of the rotor should be balanced individually, and afterwards the whole assembly.

For application of balance weights, dove-tail or channel-shaped grooves are turned on some solid part of the rotor at as large a radius as possible, the necessary weight being therefore smaller. In the case of commutators, these are usually turned by the shrink rings as shown in Fig. 11, and in rotating fields and armatures, at some place on the end shields or winding end bells.

In connection with alternators, mention should be made of the inductor type which, in view of its having no rotating windings, came up again for consideration in connection with high speeds.

With the entry of turbines it has been tried in various quarters, but not with very indicative results, and so long as a satisfactory rotating field system can be constructed it is improbable that the inductor alternator will obtain to much extent.

Stresses in a Rotating Field System.

We shall consider briefly where the stresses occur in a rotating definite-pole field structure, and where these stresses are resisted, giving at the same time some brief calculations for a 650-k.w. 1,500-r.p.m. alternator, of which a diagrammatic outline is shown in Fig. 40.

Stresses on the Pole Cores.—The pole core is subjected to a radial stress due to its own centrifugal force, together with that of the field windings, and due to its magnetic pull on the armature. The magnetic pull on the pole—

$$F_1 = B^2 A \div 72 \times 10^6,$$

where B = pole face density in lines per sq. inch,
A = area of pole face.

We have $B = 39{,}350$, for this machine,
$A = 344$ sq. ins.,

whence $F_1 = 7{,}400$ lbs.

The centrifugal force of the pole body is—

$$F_2 = 0{\cdot}0000284\ M\ R\ N^2,$$

where M = mass of pole in lbs.
R = mean radius.
N = speed in r.p.m.

The weight of one pole and its field coil is 470 lbs., and its mean radius 12·5 ins.

$$\text{R.P.M.} = 1{,}500,$$

whence $F_2 = 370{,}000$ lbs.*

The total radial pull on the pole is therefore $F_1 + F_2 = 377{,}400$ lbs. This force has to be resisted in tension at the root of the pole at the section marked *a b* (Fig. 40). The length of $a\,b = 3$ ins., and the net (iron) length of the pole parallel to shaft $= 16\frac{1}{2}$ ins.

The cross section of iron at *a b* is therefore $3·0 \times 16\frac{1}{2} = 50$ sq. ins. Hence the stress at the root of pole is—

$$\frac{377{,}400}{50·0} = 7{,}550 \text{ lbs. per sq. inch.}$$

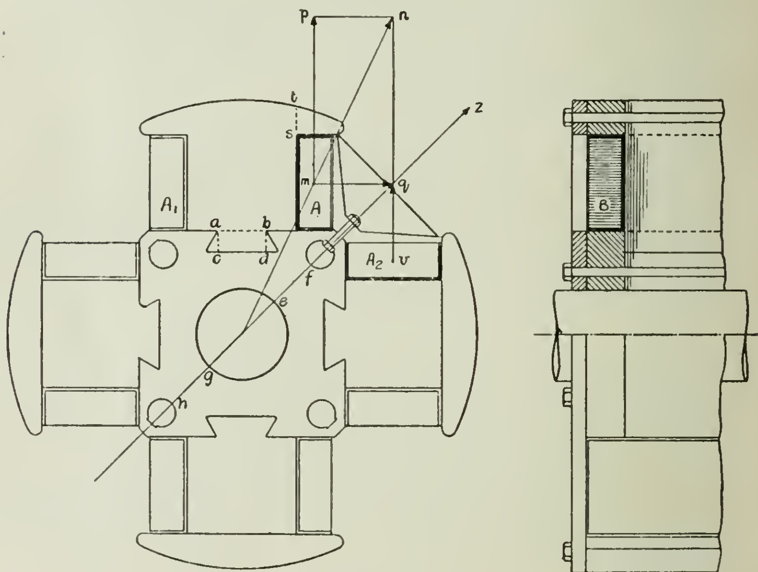


FIG. 40.

This is an average working value for wrought iron in tension, allowing a factor of safety of 7.

There is also a shearing stress on the dove-tail pieces resisted by two sections as indicated by the lines *a c* and *b d* (Fig. 40). The length of the dove-tail $a\,c = 1\frac{3}{8}$ ins. and the axial length of pole $= 16·5$ ins. Hence the area of two sections *a c* and $b\,d = 16·5 \times 1·375 \times 2 = 45·5$ sq. ins. The shear stress across corners of the dove-tail is thus—

$$\frac{377{,}400 \text{ lbs.}}{45·5} = 8{,}300 \text{ lbs. per sq. inch.}$$

* It would be more strictly correct to add to the centrifugal force of the pole iron the axial components, *m p* (Fig. 40), of that of the field coil, plus the c.f. of the coil ends, but taking on the whole force of the copper errs on the safe side.

If this stress should come out excessive it can be reduced by splitting the single dove-tail into two, which can be of smaller depth, the number of sections in shear (as *a c*) being hereby increased to four, and the total cross section resisting the force increased to any desired amount. In cases similar to those shown in Figs. 38 *a, f* and *l*, where the poles are secured by a bar or bars extending the whole length of the machine, the shear stress on the bars must be calculated, using the total area presented by all the sections of the bar in shear, and the bars must be of sufficient size to resist the stress. The shear stress across projections on the pole or hub, similar to *a c* (Fig. 40), should also be calculated, and the tensile stress on the root of the pole at its narrowest part.

Stress in the Hub.—There is a tension stress in the hub due to the centrifugal force of the poles and the hub itself, similar to the tension in the rim of a rotating flywheel. This stress tends to pull the hub in two, and its magnitude should be calculated for the minimum cross section of the hub, which occurs in this case at the lines *ef* and *g h* (Fig. 40). The tension due to the weight of the hub itself is as follows :—

The weight of half the hub is 425 lbs., and its mean radius $5\frac{1}{4}$ ins.

Its total centrifugal force is—

$$0{\cdot}0000284 \times (1{,}500)^2 \times 5{\cdot}25 \times 425 = 145{,}000 \text{ lbs.}$$

The resultant force normal to sections *ef, g h* is—

$$\frac{2}{\pi} \times 145{,}000 = 93{,}000 \text{ lbs.}$$

The stress on the sections *ef* and *g h* due to the centrifugal force of the poles is obtained from the components of the pole forces normal to the sections *ef* and *gh*.

In the case of a 4-pole structure the resultant force of two poles on the sections *ef* and *g h* is equal to the $\sqrt{2}$ times the centrifugal force of one pole. We find the centrifugal force per pole + magnetic pull equal to 377,400 lbs.

The resultant of two poles is—

$$\sqrt{2} \times 377{,}400 = 675{,}000 \text{ lbs.}$$

The total force on sections *ef, g h* is thus—

$$535{,}000 + 93{,}000 = 62{,}800 \text{ lbs.}$$

The sectional area at *ef, g h* is—

$$2 \times 3 \times 16\tfrac{1}{2} = 100 \text{ sq. ins. } (ef = gh = 3 \text{ ins.}).$$

Hence the stress is—

$$\frac{628{,}000}{100} = 6{,}280 \text{ lbs. per sq. inch.}$$

This figure will be a little greater as the forces due to the field coil supporting brackets have not been taken into account.

Stresses on the Windings.—The field coils are best dealt with by considering each side of the coil separately, *i.e.*, first the sides of the coil between adjacent poles; and second, the end parts of the coils marked A and B in Fig. 40. The centrifugal force of the mass of copper A acts in a radial direction, $m\,n$. This has two components (1) $m\,p$, the axial component, parallel to the axis of the pole, and (2) $m\,q$, the lateral component, normal to the pole axis. The axial component, $m\,p$, causes a shearing force and bending moment at the section $s\,t$ on the pole tip, which section must be sufficiently large to resist the stress. The lateral component, $m\,q$, tends to make the coil bulge and come away from the pole. It is resisted by angle brackets fixed to the hub as shown. Several methods of fixing these brackets are shown in Figs. 32 to 35. The lateral forces on the parts A and A would, if unresisted, set up a tension in the ends of the coils at B, tending to pull the coil in halves. The components $m\,q$ and $v\,q$ of adjacent coils A and A_2 give rise to a bending moment on the bracket, which is met by cross ribs of sufficient strength. These components combined give a radial resultant, $q\,z$, which force is the total tension on the retaining bolts or pins with which the brackets are fixed. This stress determines the number and size of these bolts.

It will be seen that the lateral component is smaller the narrower the pole body and the greater the number of poles. Thus with 8-pole to 6-pole machines the stresses in the angle brackets are less than in 4-pole machines. As these brackets constitute an extra amount of rotating inactive material exerting additional stresses on the rotor, an arrangement similar to that shown in Fig. 36 has some advantages. Here the lateral stress is taken up by bars passing between the top and bottom section of the field coil, through ducts between the adjacent slabs of steel of which the poles are built, secured by keys and plates on the outside of the field coil. The end portions of the field coil, B (Fig. 40), have only a radial centrifugal force, which may be taken up by an extension of the pole shoe, or a piece bolted on and to an end plate, or by means of a metal strap embracing the coil and retained on the hub at its lower ends. The latter construction is the method of the British Thomson-Houston Company and the General Electric Company of U.S.A. (Figs. 32 and 33). The strap must be of sufficient section to withstand the centrifugal force of the end portions of the coil B. In the case we have been considering, the weight of field copper on one pole is 225 lbs. Adding 10 lbs. for weight of bobbins, etc., this becomes 235 lbs. The weight of the side of the coil between poles (A) is about 87 lbs., and that of the end portion (B) 21 lbs. For A, 87 lbs. rotating at 1,500 r.p.m. at a mean radius 11 ins., the centrifugal force is 61,000 lbs. The angle which the direction of this force makes with the pole axis is 25°. Hence the axial component—

$$m\,p = 61{,}000 \cos 25^\circ = 61{,}000 \times 0{\cdot}9 = 55{,}000 \text{ lbs.},$$

and lateral component, $m\,q = 61{,}000 \sin 25^\circ = 26{,}000$ lbs.

The area of section of the pole tip at $s\,t$ is $2\frac{1}{4}$ ins. $\times$ 16·5 ins. $=$ 37 sq. ins., and hence the shearing stress is $\frac{55,000}{37} = 15,00$ lbs. per sq. inch.

The tension on the bracket bolts, $q\,z = 26,000 \times \sqrt{2} = 36,800$ lbs.

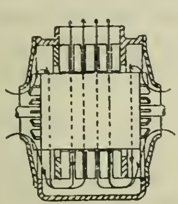


FIG. 41.

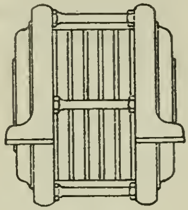


FIG. 42.

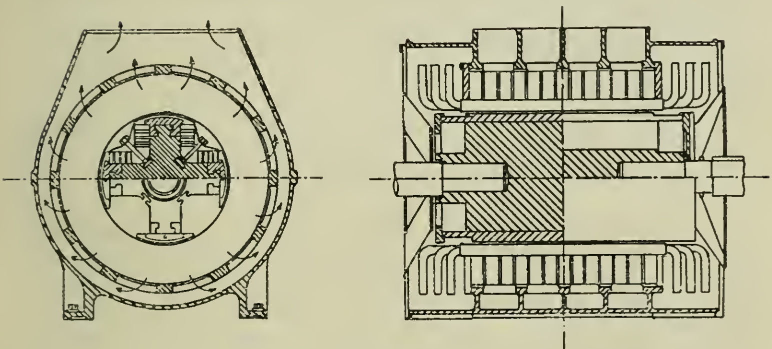


FIG. 43.

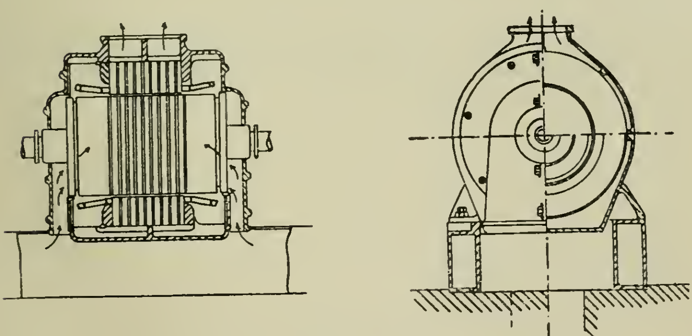


FIG. 44.

Ventilation.—There are two schemes in vogue for ventilating high-speed dynamos. The first consists in exposing freely to the air, as far as possible, all parts of the machine where losses occur and heat is generated. Besides ample provision for ducts through the cores, the

frames and end shields are pierced with numerous holes to expose the active material to the outside air. The frame for machines on this plan follows the lines of Figs. 21, 22 and 23. The extreme case of this scheme is shown in Fig. 42, which is a type of frame made for machines coupled to the Riedler Stumpf turbine. Here the outside armature core is practically totally exposed, the ends of the frame being held together with a number of tie-bolts. The air coming through the ventilating ducts has a free path out, unimpeded by any frame construction.

The other scheme, which is now much employed by manufacturers, is to enclose the machine totally in a smooth case, leaving an entry for air either at the shaft or at the base, with an outlet at the top of the machine. This cooling scheme might be classed as "induced ventilation," the draught being induced as in a chimney, and there may be a possibility of its leading to air blast cooling, as is done with batteries of transformers.

Fig. 41 represents Brown's patent for this scheme; the air enters at the shaft and spreads radially through the core ducts, leaving by the outlet at the top.

Fig. 43 shows a Parsons alternator on the same principle. Fig. 44 is one of Brown's latest constructions, in which are provided two inlets at the base of the machine, the air finding its way upward and out at the top.

In both these schemes the rotor is provided with longitudinal channels linking up with the transverse ducts. In definite pole field structures these channels invariably take the form of circular tunnels near each corner of the hub between the pole pieces. To increase the draught, metal cups are frequently put at the ends of these tunnels, which churn the air into them and through the core ducts. The angle brackets between the coils also act as fans and assist the air circulation.

In conclusion, I have to express my indebtedness to Mr. H. M. Hobart for access to and the use of much material and data used in the preparation of this paper.

SOME NOTES ON SINGLE-PHASE RAILWAY WORKING.

By H. W. Taylor, Student.

(Abstract of a Paper read before Students' Section, May 2, 1906.)

Introduction.—It is a curious fact that after having for twelve or fifteen years discussed the difficulties in the construction of a single-phase railway motor (*i.e.*, with "series" characteristics), but having nevertheless predicted that it would come, about two years ago three or four firms almost simultaneously put upon the market types of single-phase motors, more or less similar in construction, and further, they immediately undertook to equip single-phase railways, with the result that to-day we have quite a number of these alternating-current railways on which the single-phase series motor has proved its usefulness.

The Single-Phase Railway Motor.—There is no need to explain why a series excited motor suitably constructed will work with alternating current in the same way as with continuous current.

In the present practice with these single-phase railway motors, the current is usually fed into the motor at a low voltage, generally about 300. It has, however, been proposed to put the high voltage of the line direct on to the field magnets, and then to use a current transformer, so as to obtain a low voltage on the armature; but this is, in general, inadvisable, for valuable space on the magnets would be occupied with insulation. One of the chief difficulties in the design of railway motors is to get the motors into the spaces available between the wheels and between the axles and the ground, and therefore every device which enables more active material to be got into that space must be adopted.

The space factor in the armature slots of continuous-current 500-volt railway motors is about 0·4, while in polyphase traction motors working at 10,000 volts it has gone down to 0·25 and less. The increased space available in the continuous-current motor is occupied by more copper or more iron, so that the torque per ampere at starting is considerably increased.

The reason why a *lower* voltage has been adopted for the single-phase motor is that sufficient insulation has to be provided, not for the 300 *virtual* volts, but for the maximum value of the voltage, *i.e.*, $300 \times 1{\cdot}414 = 430$, so that we should expect the space factor in a 300-volt alternating-current motor to be about the same as for a 500-volt continuous-current motor.

There are at present two main types of motor in use. They may be known as the *internally* and *externally* compensated motors, for the

difference lies in the manner in which the armature reactions are compensated. The necessity for compensation may be explained as follows :—

In the continuous-current motor the ratio of the ampere-turns on the magnets to the ampere-turns on the armature is of the order of 4 : 1. Under these conditions the field is said to be "stiff," and the motor works satisfactorily without any special compensating or other anti-sparking devices. In the alternating-current motor this ratio would not be allowable, for the creation of magnetism means reactance in the path of the alternating-current, and consequently a lowering of the power factor. A "weak" field is, therefore, the first essential in the alternating-current motor, and to get the torque the armature ampere-turns must be correspondingly increased. The ratio of the magnet ampere-turns to the armature ampere-turns is thus small, and the use of some compensating device becomes a necessity, for the distorting effect of the armature under these conditions would be disastrous. Again, the elimination of the distortion means a lower armature self-induction, and therefore, again, a higher power factor.

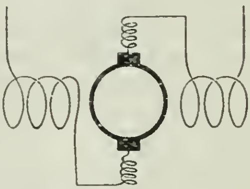


FIG. 1.

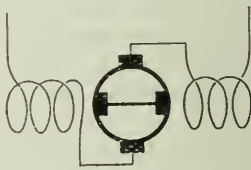


FIG. 2.

The method of external compensation is shown in Fig. 1. It is the same method as that used in present-day turbo-dynamos and widely-varying speed shunt motors, and consists essentially of a winding carrying the full motor current, placed in a position on the field magnets corresponding to that which is occupied by the current-carrying conductors in the armature. The directions of the currents in the armature and compensating windings are opposite in sense, so that the magnetic effect of the armature is more or less neutralised to an extent depending upon the distance between them (*i.e.*, upon the gap) and the relative number of conductors in the two opposing windings.

The method of internal compensation is shown in Fig. 2, and consists in making a short-circuit connection across the midway points of the commutator. It can be applied with equal effect to the compensation of continuous-current armatures, and it is curious that it does not appear to have been used for this purpose.

To simplify our explanation, let us consider its application to continuous currents. Figs. 3 and 4 represent the flow of magnetism between the poles of a bipolar machine, in the first place when no load is on, and in the second place when the armature is carrying current.

In the first case, a line between C and D divides the magnetic field

in two equal parts, so that there is no electromotive force generated between these parts of the armature windings and no current will flow between the short-circuited brushes at C and D. In the second position, however, because of the distortion of the magnetism the neutral line has been turned round to the direction E F, so that there will now be an electromotive force generated across the points C D, and if brushes at these points be short-circuited, current will flow. The direction of this current is, of course, such as to react against the magnetism which is producing it. This magnetism is the distorted component of the

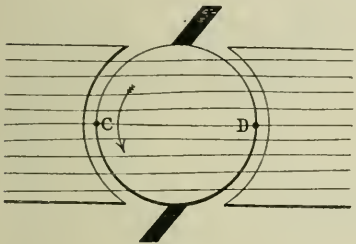


FIG. 3.

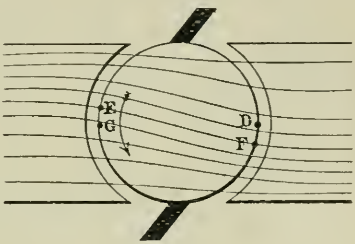


FIG. 4.

main magnetism, so the resultant action is that this is kept under control, and any tendency to distortion is at once counteracted by the current which will flow between the short-circuited brushes immediately the equilibrium of the magnetic field is disturbed.

In further explanation we have represented in Fig. 5 a bipolar armature as in Fig. 3 when it is carrying no current. When it is carrying a *motor* current distortion is produced *against* the direction of rotation, and the resulting magnetism is such as would be produced by

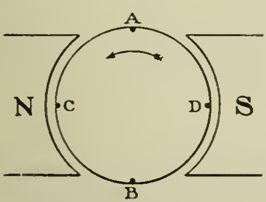


FIG. 5.

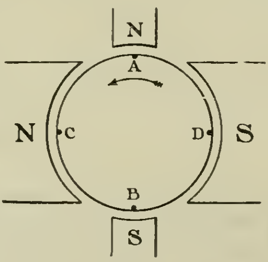


FIG. 6.

a double set of poles, as in Fig. 6. The revolving of the armature between this set of subsidiary poles will produce an E.M.F. at C and D, and the current which flows between short-circuited brushes at these points is a *generator* current, and therefore distorts *in* the direction, so that the magnetism of the subsidiary poles is thrown forward and the machine is again as it was at no load in Fig. 5.

The advantage of the internal compensation is that the action is more direct, being concerned with the very same conductors which cause the distortion, while the disadvantage is that it complicates the brush-gear. Also, over-compensation is not possible with it, because the action depends upon the distortion itself, whereas the external compensating depends upon the number of windings which have been put into the compensating coils.

A further point has to be considered in the internal compensation of the alternating-current motor, and that is the transformer action

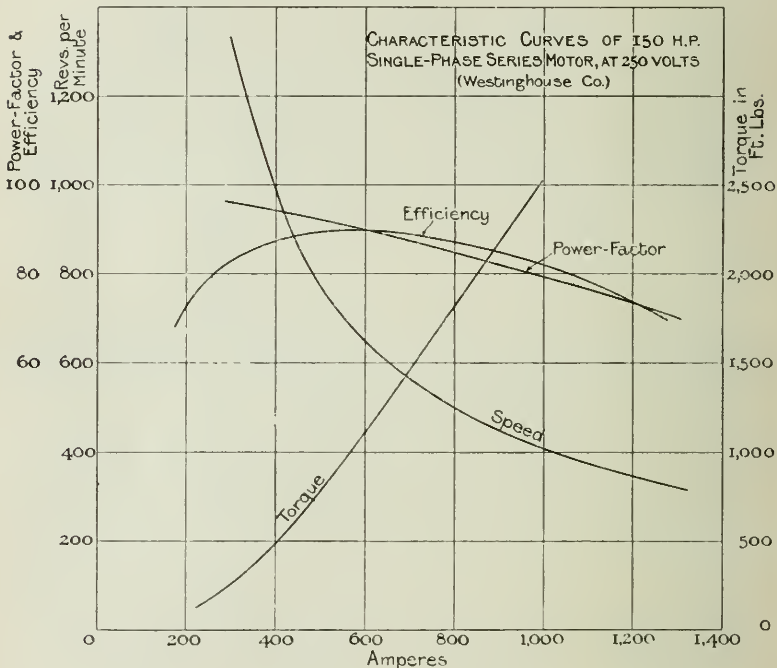


Fig. 7.

which is set up by the alternating flux passing from pole to pole through the armature coils. This has a maximum value across C D, and as C D is short-circuited, it might at first sight be thought that we have in the motor a short-circuited transformer which will draw a large current from the mains at a low power factor. But the transformer is equivalent to a current transformer, and the motor current is controlled more by the self-induction of the magnet coils due to the main flux than by the self-induction of the armature due to the leakage flux.

Characteristics of the Single-Phase Railway Motor.—The characteristics are in the main similar to those of continuous-current motors, as will be

seen by Fig. 7, which deals with a Westinghouse* slow-speed motor of 150 H.P. A circle diagram, shown in Fig. 8, sets forth in a simple way the currents and phase relations at different conditions of speed, and in some experiments carried out by Creedy,† he has shown that as long as the iron is unsaturated this diagram is accurate enough to attempt preliminary calculations with.

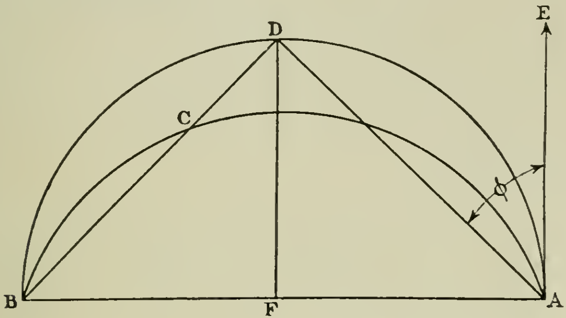


FIG 8.

Taking the lettering in Fig. 8, A D represents the value of the current, and ϕ, the angle it makes with A E, is the angle of lag at this stage. Also if A D represents the voltage drop in self-induction, C D represents the drop in resistance, and C B the remaining component of

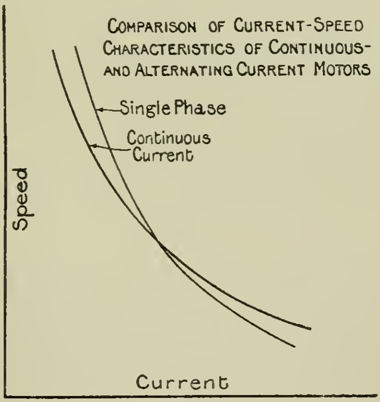


FIG. 9.

the voltage which has to be made up by the armature revolving. The speed may therefore be represented by $\frac{BC}{AD}$, and the input by D F.

The difference between the speed-current curves of the two kinds of motors is shown in Fig. 9. It is seen that in the single-phase case

* Several similar curves of other Westinghouse Single-Phase Railway Motors have been published by Schoepf in *Journ. Inst. Elec. Engs.*, vol. 36, p. 640.

† *Journ. Inst. Elec. Engs.*, vol. 35, p. 45.

the speed is higher for small values of the current, as owing to the self-induction in the motor, for any given current, the voltage which remains to be counteracted by the revolving of the armature is greater. For instance, take the case in Fig. 8; we have a back electromotive force, B C, to deal with, while if the motor was being used on continuous current, and had the same internal drop, the voltage unaccounted for would be B A — A C, and as the current is the same, the speed would be greater. Of course, a motor for continuous current, and another for alternating current, may be so designed that the speed of the continuous is always less than the other, but our deductions are with regard to the shape of the curves, *i.e.*, $\frac{ds}{dc}$, will be numerically greater for the alternating-current motor.

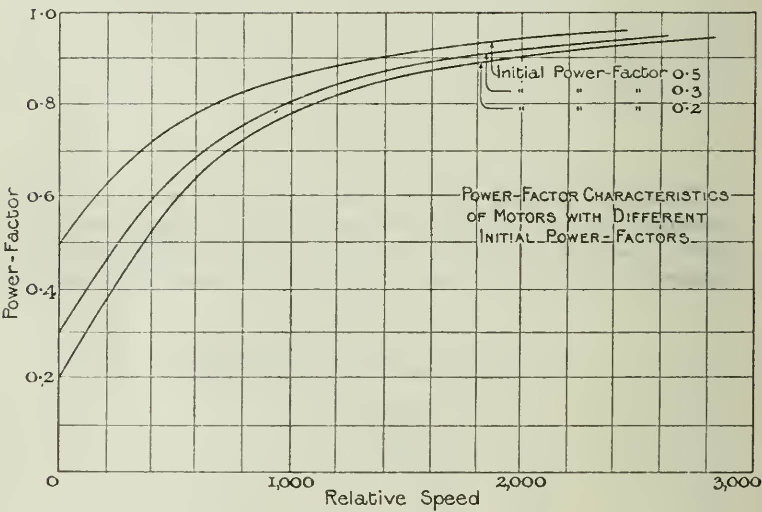


FIG. 10.

In any motor the variations of the power factor with the speed depend upon the initial power factor, *i.e.*, the power factor at start, and Fig. 10 gives curves for motors with initial power factors of 0·2, 0·3 and 0·5. Under conditions of constant acceleration these curves also represent the power factor during a train run, and this being so it is seen how important it is to have a motor with a good initial power factor.

Details in the Construction of the Motor.—The motor must be laminated throughout, as the magnetism varies not only in the armature but also in the field magnet cores and the yokes, and because of these higher iron losses, the iron should be of the best quality, and the stampings of the thinnest attainable.

In order to reduce the reluctance of the magnetic circuit to a minimum, the yoke and poles (usually four) are by some firms made up

in one piece, and not, as in continuous-current motors, in two halves. The bearing boxes cannot in this case be cast in with one of the halves of the frame, but have to form part of separate end-plates, bolted up to the frame-work castings which hold the yoke stampings.

There are two types of field magnet systems in use, namely, (1) those with a continuous iron face, looking very much like the stationary armature of a single-phase alternator, and (2) those with salient poles.

With the type of winding adopted by the Westinghouse Company the magnetising coils are placed in very large single slots, and the compensating winding is put into smaller slots distributed over the pole face, the whole looking very much like the stator of a Heyland single-phase induction motor with its large slots containing the starting coils.

These slots for the compensating coils are about the same width as the teeth between them, so that in the pole the iron area is reduced to about half, and a very reluctant cross path is provided. These points help the compensating coil in eliminating distortion.

The A.E.G. of Berlin has used magnet systems of the first type, while the Oerlikon Company has constructed motors not only with the ordinary exciting and compensating coils, but has also added a commutating pole with windings making three distinct sets of magnet windings.

The air-gap of single-phase motors is invariably smaller than the corresponding continuous-current motor, in order to reduce the number of turns on the magnetising coil, and so raise the power factor.

The armatures of the two types of motors are very similar, the only difference being that the alternating-current armature may have more ampere conductors per inch in order to make up for the lower magnetic loading. The armature should be invariably series wound, whatever the number of poles. The remark applies also to continuous-current machinery, in which at certain stages the field is considerably weakened, such as in multiple-speed motors and some types of boosters. The reason is that in a parallel wound armature the current divides into as many paths as there are poles, and the ideal case is where it divides equally. This only happens when the magnetism from each pole, and therefore the E.M.F.'s generated under the poles, are the same, and when the field is weak and the armature current great, the distortion, together with any slight irregularity in the pole, might so materially alter the flux from that pole as to confine the whole current to the region of one or two poles only. If the armature is series wound there are only two paths through it, so that polar irregularities are not so important.

The commutator should be as large as possible—in any case larger than the corresponding continuous-current commutator. The current to be commuted, owing to the lower voltage, is often greater, and in order not to overload one set of brushes, four sets may be provided, one set corresponding to each pole.

In the internally compensated motors, it is the practice of the A.E.G. to provide two sets of brushes for conducting current to the armature, and then to place around the remaining part of the commu-

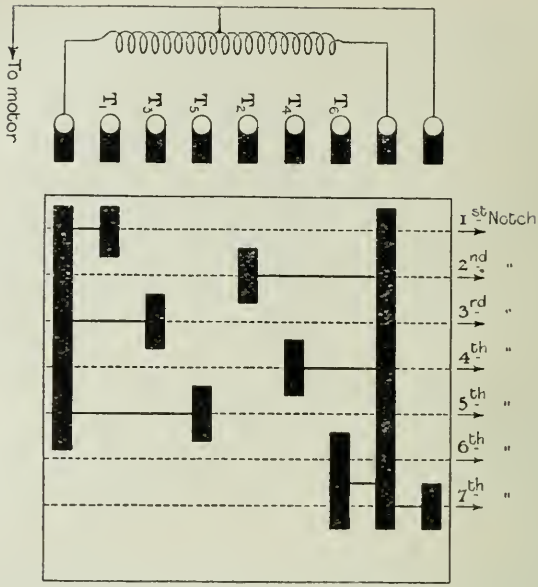

To motor
T_1
T_3
T_5
T_2
T_4
T_6
1st Notch
2nd "
3rd "
4th "
5th "
6th "
7th "

FIG. 11.

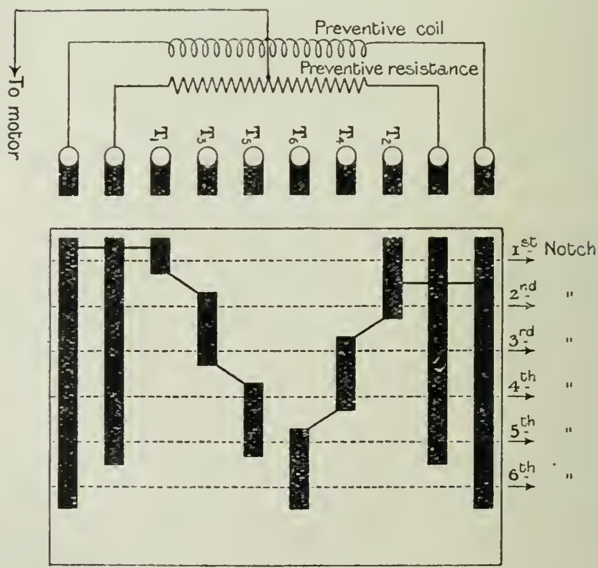

To motor
Preventive coil
Preventive resistance
T_1
T_3
T_5
T_6
T_4
T_2
1st Notch
2nd "
3rd "
4th "
5th "
6th "

FIG. 12.

tator 2, 4, 6, or 8 sets of short-circulating brushes, according to whether the motor has 4, 6, 8, or 10 poles.

Control of Single-phase Railway Motors.—The starting current is controlled by lowering the voltage on the motor by means of a static transformer. The arrangement is both simpler and more economical than in the continuous-current control, for then the current has to be cut down by means of resistances which absorb over 16 per cent. of the total power used by the train.

The simplest controller is that in which a number of steps of the transformer are connected on to the motor one after the other. Fig. 11 shows the arrangement adopted by the A.E.G. for doing this. A modification of the usual arrangement is the introduction of a choking coil, to the middle of which the connection to the motors is made, the tappings being brought to either end in succession. The reason for this choking coil is that if the first position overlaps the second, that is, if at any instant during the change from the first to the second notch the tappings T_1 and T_2 come into electrical contact, a section of the transformer windings is short-circuited, and a large current flows which has to be afterwards broken. With the present arrangement the choking coil is momentarily connected across the tappings so that the circuit is not broken during the transition period, and at the same time only a small current will flow across the short-circuited tappings.

An improvement on this arrangement is that shown in Fig. 12. Here two of the tappings are always connected to the choking coil. A small magnetising current will pass through it direct, but the main current will experience no appreciable impedance in passing through to the motors. A non-inductive resistance is also placed in parallel with the choker. The object is as follows:—Take the controller at the second notch when the tappings T_2 and T_3 are connected to the coil. Now pass to the third notch; the contact with T_2 has to be broken, and the contact with T_4 has to be made. When the contact with T_2 is broken, there is likely to be a spark with the coil alone, but with the resistance in parallel with the coil this current is not cut off, but flows through the preventive resistance. On the last notch the preventive resistance is cut out, but the coil is in all the time. In the A.E.G. controller the coil is cut out of action on the last notch, so that the voltage of the secondary of the transformer is straight on the motor.

It has been suggested that, in order to lessen the weight of the transforming apparatus to be carried on the car, the high voltage of the line should be applied straight to the field magnets of the motor, and that a smaller current transformer be used to convey the current to the armature. This arrangement is more easily applicable to the internally compensated motor because its magnet windings are not at all complicated. The principle may, however, be used for controlling purposes as shown in Fig. 13. Two motors are worked together, and while the current passes in parallel through their field windings, it passes in series through their armatures. Two tappings are provided on the main transformer, but these are only used for obtaining two

running positions. For accelerating, a current transformer is used to transform the current as it goes to the armature.

The A.E.G. of Berlin have used the series parallel principle in

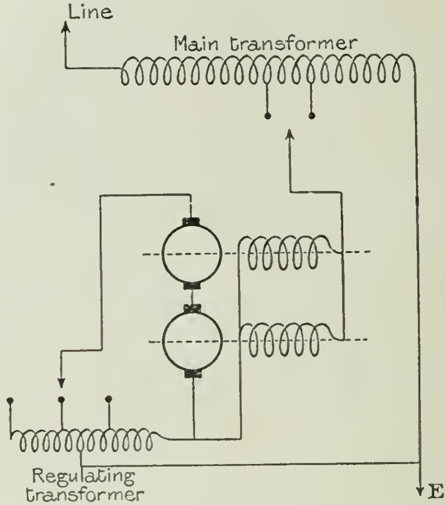
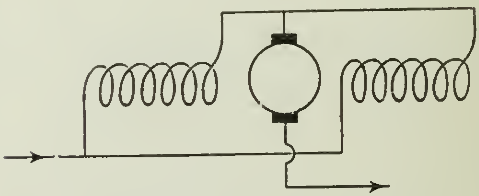
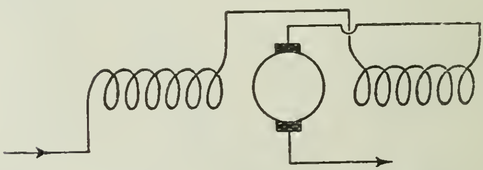


FIG. 13.



Connection of Multiple Field Coils
for Alternating Current



Connection of Multiple Field Coils
for Continuous Current

FIG. 14.

alternating-current control. The armatures are permanently in series and are connected to a current transformer for regulating purposes, while for the two running positions, the magnet coils are connected firstly in

series and secondly in parallel. In these cases of double lines, besides a possible duplication of the control equipment, an alteration in the windings of the motor, as shown in Fig. 14, has also to be made. In order to obtain the weak field with the alternating currents, parallel connections are made in the magnet coils, while for the strong field of the continuous-current motor the coils are all connected in series.

The Auto-transformer.—The type of transformer generally in these equipments is that known as an auto-transformer. It is really a choking coil wound upon a closed iron circuit connected direct across the high voltage mains, with tappings to various parts of the coils, so that lower voltages may be used.

The advantage in the use of this type is seen from the diagrams, Figs. 15 to 18, which show the currents which flow in the various coils. It is seen that the *full* current in the secondary circuit is never carried by any of the coils, and in this way a considerable economy of copper

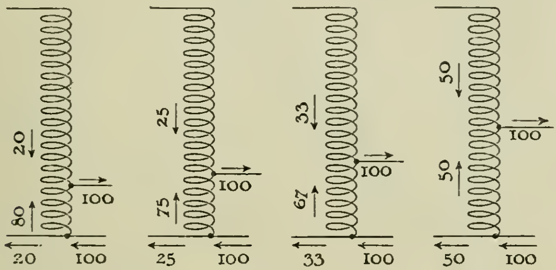


FIG. 15. FIG. 16. FIG. 17. FIG. 18.

Diagrams showing current in auto-transformer coils when tappings are made at various points.

(1) At 20% ; (2) at 25% ; (3) at 33% ; (4) at 50%.

results. In the placing of the coils with a view to getting good regulation, those to which the secondary circuit is connected must be treated in the same way as the secondary coil of an ordinary transformer, and must be sandwiched in with the other coils. With the *core* type of transformer this would be a matter of some difficulty, especially if there were many tappings, so that it is the practice to use the *shell* type of transformer for this purpose. To obtain good regulation it is also advisable to have a relatively larger proportion of the losses in the iron than is usually the practice.

Variations of Voltage during the Accelerating Period.—By a simple application of the circle diagram construction it is easy to map out schemes for suitably varying the voltage so that certain conditions are fulfilled. For instance that—

(1) The motor shall receive a constant current during the starting period, or

(2) A constant current shall be taken from the line, or

(3) There shall be a constant power demand from the line, or again,

(4) There may be a constant wattless component of the current in the line.

To show the extent to which the voltage variations are required to suit these conditions Fig. 19 has been plotted for a motor with an initial power factor of 0·3.

Distribution of Current from the Central Station.—It may be taken for granted that overhead trolley lines can be easily constructed up to

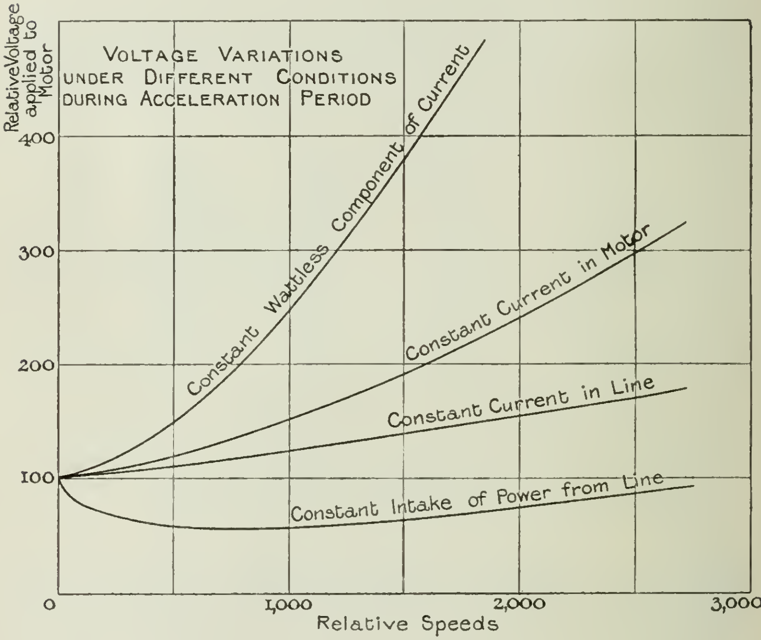


FIG. 19.

6,000 volts, and some at 10,000 volts are in contemplation. With regard to whether single or polyphase currents are more suitable for transmission purposes, it would appear that in most cases single-phase is preferable. If 3-phase were used it would be a matter of impossibility to keep the phases balanced, for each phase would have to supply different parts of the track.

Voltage Regulation in Single-phase Railway Lines.—The regulation of the voltage will be an important problem. The motors, especially at starting, are bound to take large inductive currents, and special devices will no doubt be used to keep up the voltage in spite of them. It would appear advisable to add to a good regulating

generator such a device as the Tirrel regulator, which automatically keeps up the voltage at all ordinary loads.

To get some idea of the kind of current taken from a regulating point of view, it may be pointed out that the voltage lowering effect is practically proportional to the sine of the angle of lag, and this is why it has been suggested that one of the conditions of current demand during the starting period should be that the wattless component should be constant or not exceed a given value.

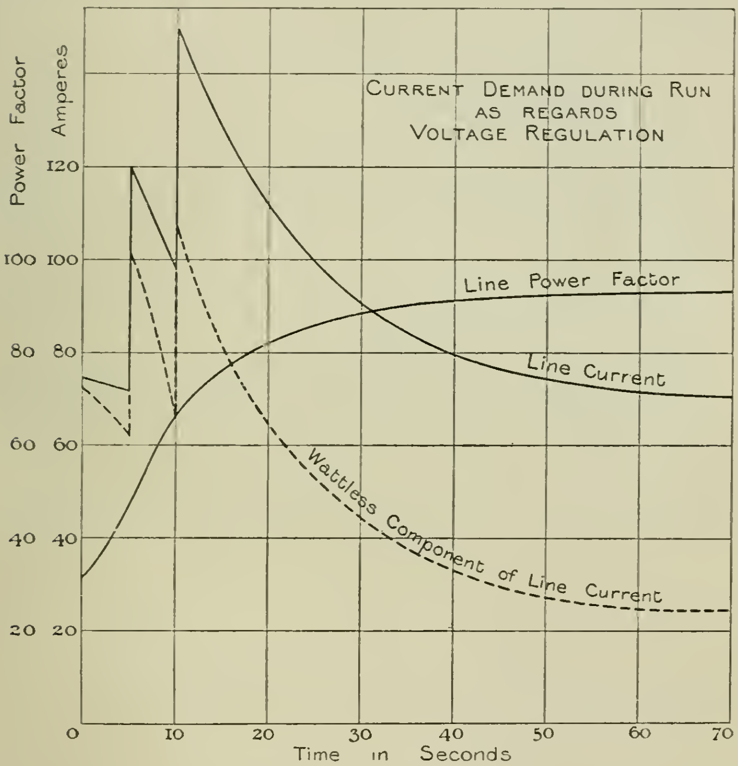


Fig. 20.

In Fig. 20 is shown the record of a train run given in the *Electric Journal* of November, 1905, and to it has been added the dotted line indicating the demagnetising component during the run.

The Resistance of the Steel Rails.—It is well known that with alternating currents the resistance of a conductor is somewhat greater than with continuous currents. This increase is the greater the higher the frequency and the higher the current density, and at very high frequencies the effect is so marked that the resistance varies, not as the area of the section, but as the periphery.

The effect is more marked in magnetic substances, and is due to the growth of the current causing eddies in the solid material, which, reacting with the current, cause it, when the variation is rapid, to keep to the outside layers of the conductor.* The action is not to be confounded with the self-induction effect caused by the flux set up around the rail.

As the best results are obtained with a section having the greatest periphery, it was thought interesting to compare the periphery of some stock sections. Thus we find, taking a constant weight of 90 lbs. per yard :—

A circular section has a periphery of			10·6	inches.
A bull-headed rail	„	„	18·5	„
A flat-bottomed rail	„	„	23·5	„
An I joist	„	„	33·0	„

It may be that eventually we shall see the return rail made up of three or four flat plates slightly insulated from one another, so that the eddies are confined to each section and, on the whole, are much reduced.

It must not be forgotten that with the high voltage trolley the currents to be returned are only about one-tenth, say, of those in the continuous-current railways of to-day.

In conclusion, the author wishes to express his indebtedness to the Electrical Company, the British Thomson-Houston Company, the Oerlikon Company, and the Westinghouse Company for information given in connection with the paper.

* It is for the same reason that compound wound dynamos with laminated poles respond more quickly to the variations in current than those with solid poles.

THE EFFICIENCY OF LAMP GLOBES.

By J. S. Westerdale, B.Sc., and F. C. Prentice, B.Sc., Students.

(*Abstract of a Paper read before Students' Section, March* 14, 1906.)

On the subject of the efficiency of lamp globes little work has been done and few figures are available. We purpose, therefore, to divide our paper into two parts, the first of which will give a brief account of work which has been done on this subject, and the second an account of some experiments which we have recently been able to carry out. In this connection our hearty thanks are due to Dr. Fleming, F.R.S., for his kindness in placing at our disposal the resources of the Pender Electrical Laboratory in University College, London.

In a paper * by Dr. W. E. Sumpner in 1893, it is stated that three glass globes were tested, the property measured being the "apparent absorption." This, it is pointed out, differs from the true absorption of the glass due to internal reflection. In the case of these globes the coefficient of reflection could not readily be measured, and hence the "apparent absorption" only is given. The source of light used was a glow-lamp, surrounded by an envelope of tracing cloth or blotting-paper to ensure a uniform distribution of light. The globes were made for arc lamps. The results were as follows:

An opal globe, almost transparent, absorbed 15 per cent. of the light.

A ground glass globe absorbed 42 per cent.

Another opal globe, "too opaque to allow any bright object placed within it to be distinguished," absorbed 39 per cent.

Details of the measurements are not stated. The figures given above are obtained by expressing the difference between the candle-power with the globe off and with it on as a percentage of the total candle-power.

With the exception of the above work of Dr. Sumpner and a recent paper by Mr. Maurice Solomon, nearly all the work on lamp globes appears to have been carried out in America.

The results of some experiments by Messrs. Guthrie and Reidhead are given by Mr. George D. Shepardson† in a paper on "The Loss of

* "The Diffusion of Light," *Phil. Mag.*, February, 1893.
† *Electrical World*, vol. 23, p. 287, 1894.

Light from the Use of Globes with Arc Lamps." The details of the experiments are given very briefly as follows: The arc lamp was arranged so that it could be rotated about an axis parallel to the photometer bench, and a large mirror was used to direct the light from the source along the bench. The standard against which the light from the arc was balanced was a 16-c.p. 50-volt incandescent lamp, connected up in rather an unusual manner. In the words of the paper, "the standard incandescent lamp was shunted around a wire resistance in series with the arc lamp." It is stated that in this way a satisfactory standard was obtained. The following are the figures given :—

	Bare Arc.	Clear Glass Globe.	Ground Glass Globe.	Opal Globe.
M.S.C.P. ...	319	235	160	144
M.H.C.P ...	450	326	215	138
Average volts on arc	53·6	50·1	49·0	49·4

From these we have calculated values for the "Mean Spherical Ratio" (M.S.R.) and the "Mean Hemispherical Ratio" (M.H.R.). The term M.S.R. is the ratio of the M.S.C.P. with the globe on, to the M.S.C.P. with the globe off, and similarly with the M.H.R.

In the above tests of Messrs. Guthrie and Reidhead these ratios come out as follows :—

Globe.	M.S.R.	M.H.R.
Clear Glass	73·8	72·4
Ground Glass	50·2	47·8
Opal	45·2	30·7

It will be seen that according to these investigators the "efficiency of lamp globes is very low—in some cases the M.S.C.P. being reduced by more than a half.

In 1895, a short paper on the subject of the efficiency of globes appeared in the *Electrotechnische Zeitschrift* by Stort. This paper was intended to show that the loss of light due to the use of globes was not so great as people supposed it to be, and the figures given seem to bear this out. They are as follows :—

	Loss of Light per Cent.
Arc alone	0
Clear glass globe	6
Opal globe	11

Few details of the methods used are given.

From 1895 to 1900 we find no account of any work done in this connection. In the latter year, however, an account of some most interesting and scientific work in connection with lamp globes appears in the *Journal* of the Franklin Institute.* The experimenters were Messrs. Williamson and Klink. They employed for their sources of light Welsbach gas mantles, using special precautions to ensure constancy of light. Their work was most laborious and precise throughout, but it deals more with the distribution of light caused by enclosing it in a globe than with the "efficiency" of the globe. It is true that the globes experimented with were chiefly gas globes, but some of the results obtained are so interesting and instructive

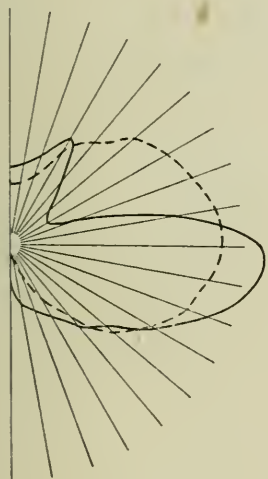


FIG. 1.

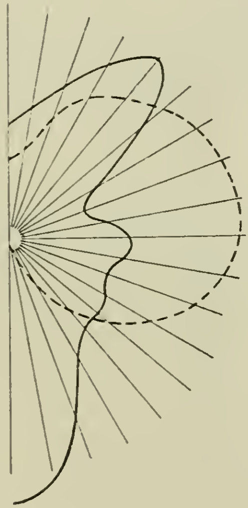


FIG. 2.

that we beg leave briefly to call attention to a few of them, confining ourselves to results obtained by the use of that type of globe known as a "holophane" globe, an account of which will be found in Crocker's "Electric Lighting," vol. 2, p. 334.

In the paper by Williamson and Klink just referred to polar curves of candle-power with and without the globes are given which clearly show that with a given source of light almost any desired distribution of it may be obtained by the use of a suitably designed holophane globe—and this with a comparatively small loss of light in the process. The full line curve Fig. 1 is the polar curve with a globe intended for horizontal distribution. As regards the shape of the globe itself, it was cylindrical, open at the top, and slightly contracted at the bottom.

* "Photometric Comparison of Illuminating Globes," *Journal Franklin Institute* vol. 149, 1900.

It will be seen that in spite of the uniform nature of the source, when the globe is in position the light is almost entirely sent out in a horizontal direction and the loss of light is only 11 per cent. Fig. 2 shows the polar curve obtained with a globe designed for vertical distribution. It will be noted that the distribution of light without globe on is similar to that in Fig. 1. Figs. 3 and 3A show distributions of light obtained from similar sources with other globes.

Another type of globe is the "Prism" globe, made in this country by the British Prism Globe Electrical Co., Ltd., of Sheffield. These globes have vertical ribs inside and are smooth outside. When used with the tubular incandescent lamps supplied by the company, the distribution of light is very satisfactory.

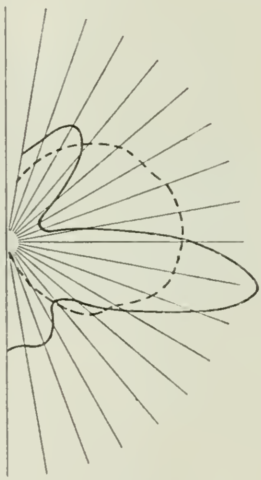


FIG. 3.

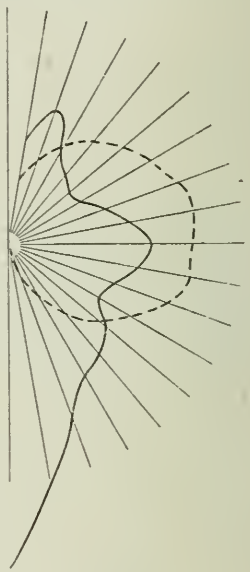


FIG. 3A.

Mr. Solomon's experiments* were carried out with Nernst lamps. The figures for the M.S.C.P.s are given below :—

Type of Lamp.	No Globe.	Clear Glass.	Frosted Glass.
A at 1 ampere ...	81·0	82·0	78·5
A at 0·52 ampere...	48·5	48·5	48·5
B at 0·24 ampere ...	13·4	13·9	13·7

* "Some Tests on Lamp Globes," *Electrician*, vol. 56, p. 91, 1905.

The M.S.C.P. is sometimes greater with a globe on, and the frosted glass seems to be as efficient as the clear. Of course, when a Nernst glower is surrounded by a globe it burns at a higher temperature and so gives more light. This, however, does not explain the efficiency of the frosted globe.

An interesting series of articles on "Reflectors, Shades and Globes" by Messrs. Cravath and Lansingh appeared recently in the *Electrical World*. Amongst many other experiments, they obtained the M.S.C.P. of a 16-c.p. glow lamp. They then etched the bulb with acid and again measured the M.S.C.P. The absorption of light amounted to 11·5 per cent. An incidental advantage in the use of holophane globes is mentioned, namely, that if allowed to get dusty less light is lost than with ordinary globes.

It will be seen that little work has been done on *arc* lamp globes, and we have nowhere found polar curves given for arcs surrounded by globes. It was with the idea of obtaining such curves and determining the corresponding mean spherical and hemispherical ratios that the experiments were made which we now proceed to describe.

The Efficiency of Lamp Globes.

All ordinary laboratory apparatus for use in photometry is designed to measure the candle-power of a source of light which is small. In the case of a translucent globe enclosing a source of light, the globe itself becomes to a certain extent the source of light, and the distance between the globe and the photometer must be great in comparison with the diameter of the globe.

We decided to measure the mean spherical and mean hemispherical ratios by means of a source of light of the nature for which the globes were designed.

The terms mean spherical ratio and mean hemispherical ratio have already been defined. These values depend upon the source of light and, to a small extent, on the mechanism; hence they are not necessarily absolutely constant for any given globe. They cannot vary, however, to a great extent from values obtained under conditions as nearly as possible similar to the conditions under which the globe would be used in practice.

The apparatus constructed was as follows :—

A beam of wood A B, 3 ins. $\times$ $1\frac{7}{8}$ ins. and of length 4 ft. 6 ins., was pivoted at a point A by means of a bolt (see Fig. 4). This beam could be rotated in a plane at right angles to the photometric bench. Near the end of A B, 3 ft. 6 ins. from the centre, an arm, B C, was arranged to carry the arc mechanism, and could be turned about a horizontal axis. The arm B C was constructed so that the arc mechanism could be quickly brought into a vertical position when the beam was inclined at any angle.

The beam A B is pivoted at a point $7\frac{1}{2}$ ins. below the centre line of the photometric bench, so that the arc moves very approximately in a circle, with its centre in a line with the photometer and the standard

lamp. A large mirror was placed with its centre at the point about which the arc rotated, and was arranged so that it could be swivelled about an axis in line with the bench, and also about an axis at right angles to the latter.

The arc used was hand-fed in such a way that it remained central in the globe during a complete set of readings. The P.D. of the arc was kept constant at 50 volts, and the current at 6 amperes during the whole of these experiments. For convenience in enclosing the arc in the globe and removing it without in any way altering the conditions, the arc was inverted, the positive carbon being the lower

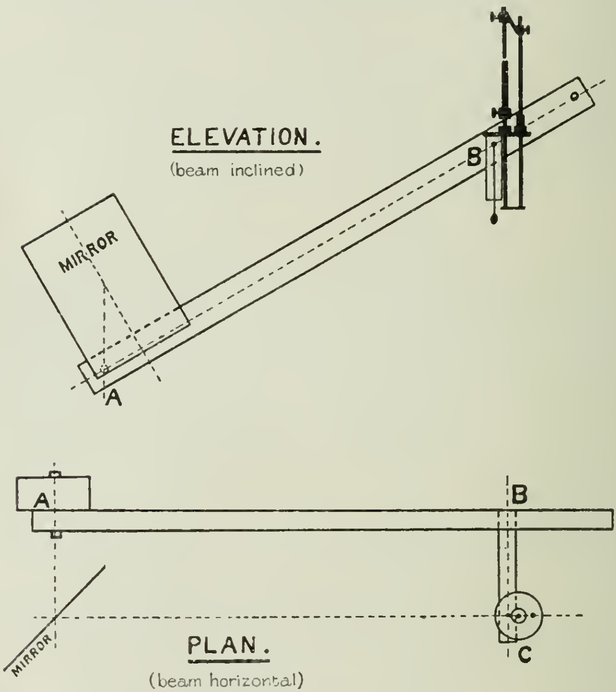


Fig. 4.

one. Precautions were taken to prevent stray light reaching the photometer.

The method of procedure was as follows :—

A globe was placed over the arc, and each of the authors in turn obtained four successive balances on the photometer. The globe was then carefully removed, and eight balances were obtained in the same way for the naked arc. Another globe was then placed over the arc, and eight measurements of the candle-power were made again. The second globe was then removed, and the beam shifted to its next position. The whole process was repeated every 15 degrees.

The coefficients of reflection of the mirrors used were measured and found to be—

73·7 % for mirror No. 1 ($15\frac{1}{2}$ ins. × $10\frac{1}{2}$ ins.)

and

85·0 % for mirror No. 2 (14 ins. × 14 ins.).

Secondary Standards.—The lamps used to balance the light of the arc on the photometer screen were ordinary incandescent lamps. It was found necessary to use three different standards for various angles. The c.p.s of these were measured by keeping them at a fixed voltage and balancing them against a Fleming large bulb standard incandescent lamp having a known c.p. at a known current. This current was measured on a Crompton potentiometer, and kept constant during the calibration of the secondary standards.

Candle Powers of Secondary Standard Lamps.

8 c.p. lamp	burning	at	40 volts	...	3·43 c.p.
8 c.p. ,,	,,	,,	50 ,,	...	13·80 c.p.
32 c.p. ,,	,,	,,	100 ,,	...	32·3 c.p.
32 c.p. ,,	,,	,,	100 ,,	...	34·7 c.p.

A Lummer Brodhun prism photometer was used. The photometer was kept fixed, and the secondary standard moved to obtain a balance.

The negative carbons were 9 millimetres in diameter and the positives 12 millimetres, the latter being cored.

The following tables give the results in a condensed form, the symbols employed being as given below :—

^{d}arc = Distance of secondary standard from photometer-screen for naked arc.
D = Distance of arc from photometer.
C.P. arc = Candle-power of arc alone.
^{d}globe = Distance of secondary standard lamp from photometer-screen when arc is enclosed in globe.
C.P. globe = Candle-power with arc enclosed in globe.

$$\frac{\text{C.P. of standard for arc}}{{}^{d}\text{arc}^2} = \frac{\text{C.P. arc} \times \eta}{\text{D}^2}$$

$$\therefore \text{C.P. arc} = \frac{\text{D}^2}{{}^{d}\text{arc}^2} \times \frac{\text{C.P. secondary standard for arc}}{\eta}.$$

In same way—

$$\text{C.P. globe} = \frac{\text{D}^2}{{}^{d}\text{globe}^2} \times \frac{\text{C.P. secondary standard for globe}}{\eta}.$$

$$\eta = \text{efficiency of mirror.}$$

TABLE No. 1.

Thick Alabaster Globe, 10 ins. Diameter.

η for Mirror = 73·7 per Cent.

Angle.	d_{Arc} in Inches.	D Inches.	$\frac{D^2}{d_{Arc}^2}$	C.P. of Secondary Standard to Balance Arc.	C.P. Arc.	d_{Globe} Inches.	C.P. of Secondary Standard to Balance Globe.	$\frac{D^2}{d_{Globe}^2}$	C.P. Globe.
0°	—	155·5	—	—	—	39·4	13·8	15·6	292
15°	69·7	156·0	5·00	3·43	23·0	60·4	32·3	6·7	294
30°	49·8	156·5	9·87	32·30	433·0	54·2	32·3	8·4	365
45°	34·3	156·8	20·90	32·30	920·0	55·2	32·3	8·1	355
60°	35·3	157·0	19·80	32·30	871·0	57·6	32·3	7·4	326
75°	31·0	157·0	25·60	13·80	480·0	41·5	13·8	14·3	268
90°	70·1	157·5	5·06	13·80	94·7	45·3	13·8	12·1	226
105°	73·8	157·3	4·54	13·80	85·0	50·6	13·8	9·7	181
120°	69·0	157·5	5·21	13·80	97·7	54·2	13·8	8·5	158
135°	71·8	157·5	4·80	13·80	90·0	59·4	13·8	7·0	131
150°	92·6	157·5	2·89	3·43	13·5	75·7	13·8	4·3	81
165°	—	157·3	—	—	—	88·3	13·8	3·2	59
180°	—	157·0	—	—	—	86·4	13·8	3·3	62

TABLE NO. 2.

Alabaster Globe, 13 ins. Diameter.

η for Mirror = 85 per Cent.

Angle	d_{Arc} in Inches.	D Inches.	$\frac{D^2}{d_{Arc}^2}$	C.P. of Secondary Standard to Balance Arc.	C.P. Arc.	d_{Globe} Inches.	C.P. of Secondary Standard to Balance Globe.	$\frac{D^2}{d_{Globe}^2}$	C.P. Globe.
0°	—	155·5	—	—	—	39·0	13·80	15·9	258
15°	—	156·0	—	—	—	33·5	13·80	21·6	351
30°	22·7	156·5	47·6	13·80	774·0	26·2	13·80	35·7	580
45°	21·4	156·8	24·9	32·30	945·0	38·5	32·30	16·6	631
60°	33·6	157·0	21·9	32·30	833·0	40·9	32·30	14·7	558
75°	45·8	157·0	11·7	32·30	444·0	49·7	32·30	10·0	380
90°	78·7	157·5	4·0	32·30	152·0	61·2	32·30	6·6	251
105°	70·4	157·3	5·0	13·80	81·0	45·4	13·80	12·0	195
120°	51·2	157·5	9·5	13·80	154·0	39·6	13·80	15·8	257
135°	54·6	157·5	8·3	13·80	135·0	43·6	13·80	13·0	211
150°	58·3	157·5	7·3	3·43	29·5	24·6	3·43	41·0	165
165°	—	157·3	—	—	—	27·6	3·43	32·5	131
180°	—	157·0	—	—	—	28·3	3·43	31·0	125

TABLE No. 3.

Clear Glass Globe, 13 ins. Diameter.

η for Mirror = 85 per Cent.

Angle.	d_{Arc} in Inches.	D Inches.	$\frac{D^2}{d_{Arc}^2}$	C.P. of Secondary Standard to Balance Arc.	C.P. Arc.	d_{Globe} Inches.	C.P. of Secondary Standard to Balance Globe.	$\frac{D^2}{d_{Globe}^2}$	C.P. Globe.
0°	—	155·5	—	—	—	75·8	3·43	4·2	17·0
15°	—	156·0	—	—	—	—	—	—	—
30°	22·7	156·5	47·6	13·80	774·0	24·3	13·80	41·5	674
45°	21·4	156·8	24·9	32·30	945·0	34·2	32·30	20·9	794
60°	33·6	157·0	21·9	32·30	833·0	36·3	32·30	18·7	710
75°	45·8	157·0	11·7	32·30	444·0	45·5	32·30	11·9	452
90°	78·7	157·5	4·0	32·30	152·0	93·0	32·30	2·9	110
105°	70·4	157·3	5·0	13·80	81·0	107·0	32·30	2·2	84
120°	51·2	157·5	9·5	13·80	154·0	53·5	13·80	8·7	141
135°	54·6	157·5	8·3	13·80	135·0	55·4	13·80	8·1	131
150°	58·3	157·5	7·3	3·43	29·5	48·9	3·43	10·4	42
165°	—	157·3	—	3·43	—	73·4	3·43	4·6	19
180°	—	157·0	—	3·43	—	73·3	3·43	4·6	19

TABLE No. 4.

Opalescent Globe, 13 ins. Diameter.

η for Mirror = 85 per Cent.

Angle.	d_{Arc} in Inches.	D Inches.	$\frac{D^2}{d_{Arc}^2}$	C.P. of Secondary Standard to Balance Arc.	C.P. Arc.	d_{Globe} Inches.	C.P. of Secondary Standard to Balance Globe.	$\frac{D^2}{d_{Globe}^2}$	C.P. Globe.
0°	—	155·5	—	—	—	29·7	13·80	27·6	448
15°	63·0	156·0	6·1	13·8	99·0	—	13·80	—	396
30°	35·9	157·0	19·1	34·7	780·0	45·9	34·70	11·7	478
45°	33·4	157·0	22·1	34·7	903·0	42·4	34·70	13·7	560
60°	35·8	157·0	19·2	34·7	784·0	43·6	34·70	12·9	527
75°	50·2	157·0	9·8	34·7	400·0	51·7	34·70	9·2	375
90°	96·5	157·0	2·6	34·7	106·0	63·1	34·70	6·2	253
105°	102·9	156·0	2·3	34·7	94·0	72·3	34·70	4·7	192
120°	97·1	156·0	2·6	34·7	106·0	79·3	34·70	3·9	159
135°	47·3	156·0	10·9	13·8	177·0	45·0	13·80	12·0	195
150°	—	156·0	—	—	—	27·3	3·43	32·6	132
165°	—	156·0	—	—	—	28·9	3·43	29·2	118
180°	—	156·0	—	—	—	30·7	3·43	25·8	104

TABLE NO. 5.

Prism Globe, 13 ins. Diameter.

$\eta = 85$ *per Cent.*

Angle.	d_{Arc} in Inches.	D Inches.	$\frac{D^2}{d_{Arc}^2}$	C.P. of Secondary Standard to Balance Arc.	C.P. Arc.	d_{Globe} Inches.	C.P. of Secondary Standard to Balance Globe.	$\frac{D^2}{d_{Globe}^2}$	C.P. Globe.
0°	—	155·5	—	13·80	—	94·2	13·80	2·7	43·9
15°	63·0	156·0	6·1	13·80	99	62·8	13·80	6·2	100·6
30°	35·9	157·0	19·1	34·70	780	46·7	34·70	11·2	457·0
45°	33·4	157·0	22·1	34·70	903	37·9	34·70	17·2	702·0
60°	35·8	157·0	19·2	34·70	784	37·1	34·70	17·9	731·0
75°	50·2	157·0	9·8	34·70	400	47·4	34·70	11·0	449·0
90°	96·5	157·0	2·6	34·70	106	75·2	34·70	4·3	175·0
105°	102·9	156·0	2·3	34·70	94	87·6	34·70	3·2	131·0
120°	97·1	156·0	2·6	34·70	106	87·6	34·70	3·2	131·0
135°	47·3	156·0	10·9	13·80	177	53·8	13·80	8·4	136·5
150°	—	156·0	—	3·43	—	52·6	3·43	8·8	35·5
165°	—	156·0	—	3·43	—	57·6	3·43	7·3	29·4
180°	—	156·0	—	—	—	55·7	3·43	7·8	31·5

The polar diagrams for these globes were drawn. From the polar diagrams the Rousseau diagrams are obtained in the usual way. The area of the Rousseau diagram when divided by its base gives the mean spherical candle-power. The mean hemispherical candle-power is, in the same way, the mean ordinate of the area from 0° to 90°. These curves were plotted both for the arc only and for the globe over the arc, and the M.S.C.P.s obtained, and from these values we obtained, as explained above, the mean spherical ratio and the mean hemispherical ratio.

These results are tabulated in Table No. 6.

TABLE No. 6.

	Globe.	M.S.C.P.		M.S.R.	M.H.C.P.		M.H.R.
		Arc only.	Arc enclosed in Globe.		Arc only.	Arc enclosed in Globe.	
In.				%			%
10	Alabaster	319	226	71·0	563	304	54·0
13	Alabaster	346	339	98·0	592	473	79·9
13	Clear	346	308	89·0	592	520	87·9
13	Opalescent	342	343	100·0	576	476	82·8
12	Prism	342	306	89·5	576	500	86·9

Conclusions drawn from these results :—

In the case of the arc lights the c.p. drops very rapidly after about 70°, and never rises to any great value again. This is due to the well-known effect of the negative carbon at angles above 90° cutting off light from the crater of the positive carbon. Also the arc mechanism cuts off the light at the last three points. The platform on which the globes rested was only wide enough to take the rim of the mouth of the globe. Now in the case of the clear glass globe this same effect results, since the light is dispersed and reflected very little by the glass. But in the case of the alabaster and opalescent globes, due to dispersion, the globe itself becomes to a certain extent the source of light, and so, even though the arc mechanism cuts off all light when the globe is off, it does not do so when the globe is on, and we get a measurable c.p. for the globes right up to 180°. There is also another important reason why the c.p. in directions above 90° is greater with the globe on than with the arc alone. Light from the crater falls on to the lower parts of the globe, and is partly reflected back. This reflected light is partly emitted through the upper part of the globe, thus increasing the c.p. in these directions.

In conclusion, we wish to tender our thanks to Messrs. Hattersley and Davidson, Messrs. Johnson and Phillips, the Electrical Company, and the Brockie Pell Arc Lamp Company, who have kindly lent us globes.

NOTES ON ELECTRICAL CONDUCTIVITY.

By WILLIAM BROWNING, Wh. Ex., Student.

(Abstract of a Paper read before the Students' Section at Manchester, March 23, 1906.)

The term conductivity, as used by the electrical engineer, denotes current conducting capability, which is generally compared with some standard, either the recognised Matthiessen's standard or some other arbitrary standard. The term conductivity is here used in a general sense.

Consider the equation of Ohm's Law—

$$C = E/R.$$

This may be written—

$$C = E \times \text{Conductivity}.$$

If in a section of a circuit a current of one ampere flows under an applied pressure of one volt, the conductivity of the section will be unity, and, dividing the current by the volts, we have as a result :—

$$\text{Conductivity} = \text{Amperes per volt}.$$

The unit of conductivity has been given the name of Mho (Ohm spelt backwards), but the term has not an extended use. Conductivity is in general better expressed as amperes per volt. The conductivities dealt with in this paper would, when expressed in terms of amperes per volt, give very large numbers; to obviate this the conductivities are given in terms of amperes per millivolt.

In order to make comparisons between the conductivity of areas of different sizes the conductivity must be reduced to that of unit area. The expression now becomes amperes per square inch per millivolt.

This as it now stands may be applied to contacts, but when applied to continuous conductors the length has to be taken into account.

Problems on electrical circuits can be readily and easily worked out by using conductivities instead of resistances. This is more evident in the case of alternating-current circuits, where the term corresponding to conductivity, viz., "admittance," is used.

In the electrical circuits employed in practice various joints occur in the conductors. These are either temporary—as, for instance, switches, circuit-breakers, sliding contact-makers—or they are permanent—as, for instance, connections to bus-bars and instruments, rail bonds, etc. The great losses which occur in these contacts when

heavy currents are employed may be seen from the Table at the end. The figures are averages of many readings and are in no way exceptional.

What actually takes place at the junction of two metals when a current flows it is difficult to say. The outline theory is as follows: A current of electricity is accompanied by a motion of the electrons, a number of which seem to be but loosely connected to the molecules of the substance, and the conductivity depends in some way upon these loosely connected electrons. The resistance to the flow of electricity has been found to be an expression including the specific inductive capacity and a number which depends upon the vibrations of the electrons and of the electric field. Further investigations show that conductors of electricity ought also to conduct light, and this is found to be so, because metals in thin films are quite transparent to light and generally give very beautiful colours; gold, for instance, is of a beautiful green by transmitted light.

When a current of electricity has to pass a joint the motion of the electrons in one piece of the conductor has to be transmissible to the electrons of the adjoining conductor. If the medium which fills the space between the conductors is nonconducting, as is the case with contacts in air, the foregoing conclusion demands that the surfaces must be in molecular contact; but, however well they are caused to make contact, unless the surfaces are destroyed, as by welding or by amalgamating with mercury, there is an effect which is known as the contact resistance. This is not altogether of the same nature as the resistance of a continuous conductor, but is in part caused by the reflection of the wave motion of the electrons at the contact. A second factor is evident when the actual nature of the contact between two surfaces is considered, *i.e.*, the hill and dale character of the surface. The surfaces touch at comparatively few points, and at these the current gathers. This gathering causes a drop in volts, due to the increased current density at the points. The resistance of a metal contact seems to increase with the current flowing, but this may be due to the heating of the contacts. The curve in Fig. 1 shows a result which was obtained from readings taken on two smooth brass surfaces in contact. They were heated up by passing a large current, then the readings of amperes flowing and volts drop were taken quickly, commencing from the low values. The point, however, requires further investigation before the result can be confidently accepted.

When the two metal surfaces are dissimilar the phenomenon of E.M.F. of contact, and with it an apparent change in the resistance of contact, with a change in the direction of the current, is observed. Another remarkable effect, observed by Edison, is the change in frictional resistance between two surfaces when a current flows across the contact. There seems to be more than a simple transference of current taking place at the contact. The molecular nature of the surface may be changed.

The conductivity of a contact varies almost directly as the

mechanical pressure between the contacts up to a certain value of the pressure. This is shown very clearly in Fig. 2.

The tests were carried out on two brass circular discs, 1·54 sq. ins. in area, which were so arranged that the pressure between them could be varied at will. The resistance was obtained by measuring the volts drop across the contact when a current of known strength was passing. The arrangement has its disadvantages, as the true resistance could only be measured when practically no current is flowing (such would be the conditions when using some form of the potentiometer method). On the other hand, a contact generally carries a current.

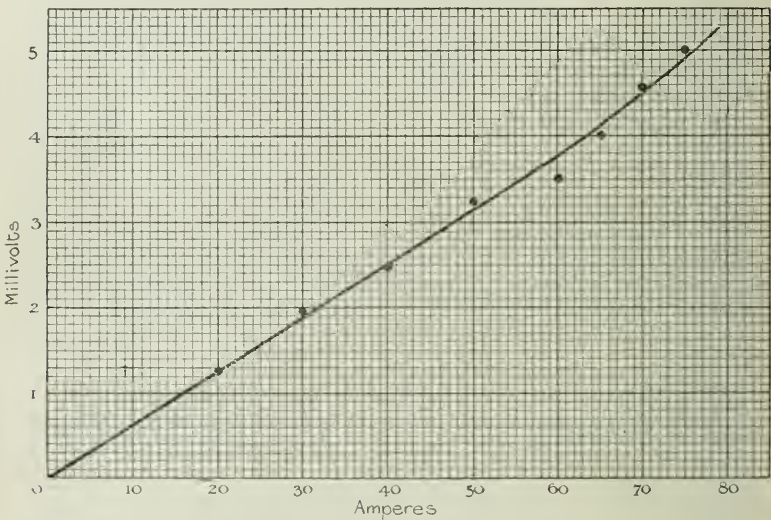


FIG. 1.—Curve showing the relation between the current passing and the volts drop across a metal contact.

It was found when the results were examined that the conductivity curves gave more information than the resistance curves; however, both sets have been placed in the diagram. All the results here given were obtained at a constant current density of 32·45 amperes per square inch. The ordinates of the resistance curve are in microhms, and the ordinates of the conductivity curves are in amperes per square inch per millivolt. Each one of the curves is a typical example of a certain set of conditions.

The brass contacts were cleaned. The resulting Curve I. indicates the increase of conductivity with pressure. Different conditions were obtained by electrolytically depositing copper, first with a very fine deposit and second with a rough deposit, this deposit being made at as high a current density as possible. The Curves II. and III. show the results obtained. Curve IV. was obtained from the copper-coated con-

tacts after they had been rubbed together to reduce the surface to a condition of smoothness. Curve V. shows the results obtained from the brass contact and tinfoil. The readings are for one contact only. The effect of the E.M.F. of contact was eliminated by taking the drop across both contacts and dividing by two. This would not, however, get rid of any Peltier effect caused by unequal heating of the two contacts if one had a greater resistance than the other. In each of the five cases it is seen that the conductivity becomes constant after a certain value of the pressure has been reached. This pressure varies with the nature of the surface.

For the plain brass it is about 35 lbs. per square inch.

For the fine copper deposit it is about 32 lbs. per square inch.

For the rough copper deposit it is about 27 lbs. per square inch.

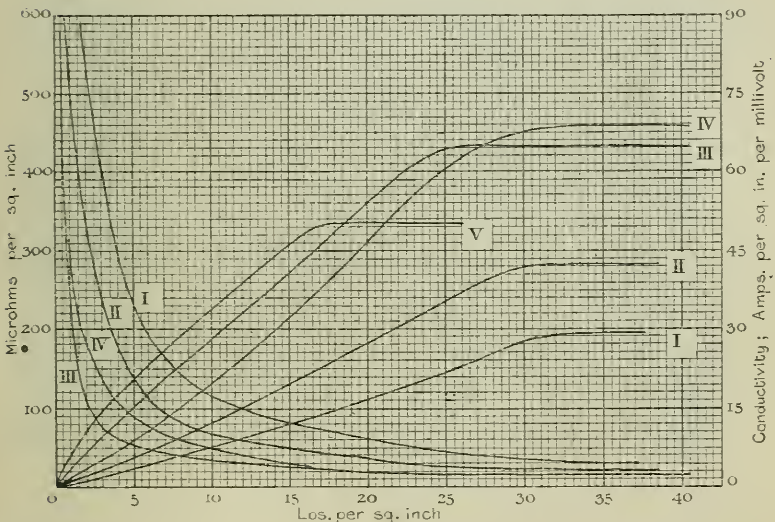


FIG. 2.—Curves showing the relation between the conductivity, at constant current density, and the mechanical pressure for various kinds of contact surfaces.

While for the last case, after polishing the surfaces, this critical pressure is increased to 33 lbs. per square inch, in the case of the soft tinfoil the pressure is only 17 lbs. per square inch.

This critical pressure seems to depend upon two factors—the hardness of the metal and the nature of the surface. The greater the roughness of the surface, the less is the normal pressure required to make the actual bearing surfaces come into molecular contact. Again, the bearing points are not even, and those on which the pressure bears most will give.

Tinfoil is sometimes placed between permanent contacts to improve the conductivity. This is only a benefit when the surfaces are uneven, for the effect of the second contact which is introduced

makes the conductivity of fairly true surfaces worse, at the higher pressures; although at the low pressures the tinfoil rather improves matters. But on the whole tinfoil does not improve the conductivity greatly.

The effect of oil between the contacts was next examined. The curves of conductivity shown in Fig. 3 were obtained under similar conditions, which as regards current density were similar to the conditions existing for the curves for the dry contacts. The tests were carried out on the polished copper contacts which gave Curve IV.

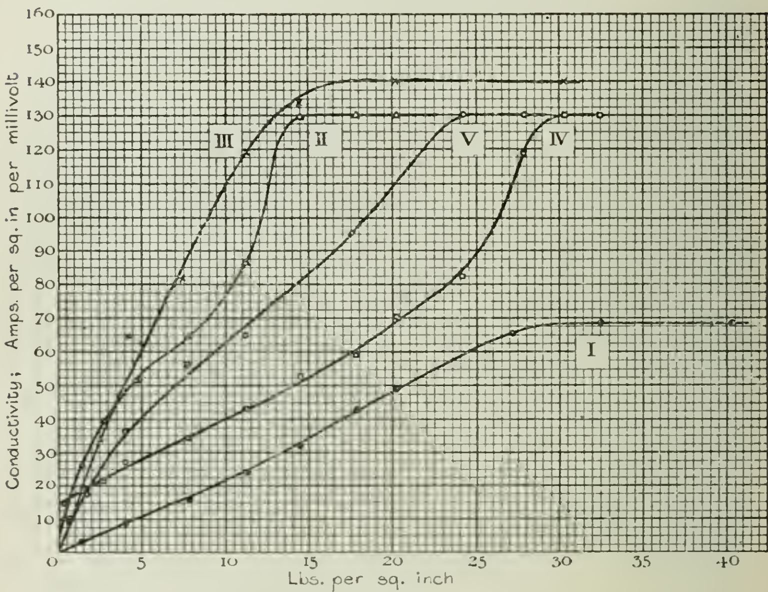


FIG. 3.—Curves showing the relation between the conductivity and the mechanical pressure for smooth copper contacts under varied conditions—I. contacts dry; II. contacts with much oil; III. contacts with thin film of oil; IV. contacts with much vaseline; V. contacts with thin film of vaseline.

in Fig. 2. This curve is reproduced in Fig. 3 and is numbered I. Resin oil and vaseline were used.

Curve II. shows effect when the contacts are practically immersed in the oil, as is the case with oil switches.

Curve III. shows effect of only a thin film of oil, such as can be put on by an oiled rag.

Curve IV. was obtained under similar conditions to II., with vaseline instead of oil, and Curve V. corresponds to Curve III.

At the high pressures, when the conductivity has reached its maximum value, oil and vaseline both increase the conductivity of the contact in about the same ratio; but at the lower pressures there is a marked difference in the behaviour of the contacts' conductivity.

The increase in conductivity when oil is present may be due to the filling up of the minute valleys with the oil, which has a finite resistance, while the air which previously filled the space has practically an infinite resistance.

The effect of the oils upon the critical pressure is more difficult to explain. It may be that the molecular forces in the oil come into play when the film becomes very thin, and then the actual pressure between the surfaces would be greater than the applied pressure. The viscosity of the oil seems to have an influence on the result also. The oil has also a cleaning action, and prevents any oxide forming on the surfaces.

To ensure that all the surface is bearing it is usual to laminate switch contacts, so that each surface may bear, without any con-

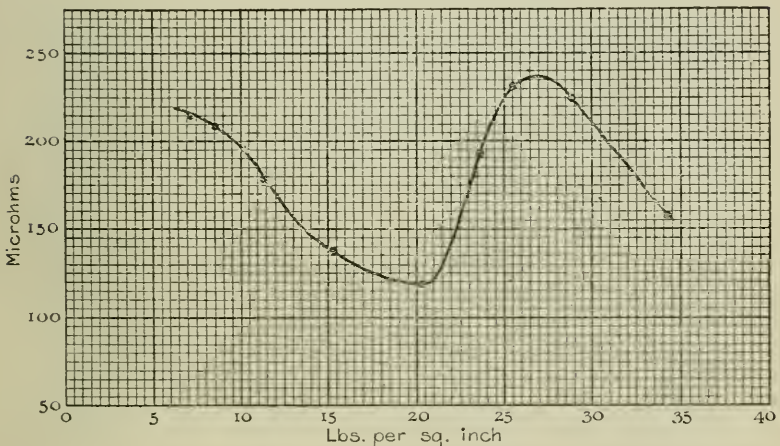


FIG. 4.—Curve showing the relation between the resistance and the mechanical pressure on the contact surfaces, at constant current, of a circuit-breaker (18 laminations, each $\frac{1}{32}$ inch thick).

nection with the neighbouring strips, and this introduces a new factor into the conductivity of the contact. The pressure on the contact is put on by the springiness of the laminations, and as the laminations are pressed down they spread out on the surface and often tilt so that the whole surface of the edge is not in contact. The curve in Fig. 4 shows very clearly the effect of the tilting. The example must only be taken as a type showing the action of the tilting of the laminations. The contact was on an 800-ampere Schuckert circuit-breaker. The final pressure was 35 lbs. per square inch.

The question of the limiting value of the current density is mainly decided by the design of the switch. The density may be pushed up until it commences to cause heating, which must not be allowed to occur, as a heated contact soon deteriorates. The heating point is decided by the amount of metal in the contact. The contacts in the controller of a tram are made by a stiff spring bearing on a roller.

Now the contact area in this case is practically little more than a line, and yet such contacts carry 50 or 60 amperes without becoming hot, because of the large mass of metal behind them which is capable of conducting away the heat and dissipating it.

The contact resistances of rail bonds are of special interest to tramway engineers. Little can be done to the rails themselves, as the high conductivity iron does not wear well. The only way open, then, is to improve the joints, and this is done by either bonding or welding the rails into one continuous length.

There are two classes of bonds : (1) the copper bond, in which the joint is bridged over by a copper strip or bar, the strip being secured to lugs which are riveted to the rails ; and (2) plastic bonds, in which the fish-plate is made to carry the current by being connected to the rail by plugs of a plastic alloy, which bear on amalgamated surfaces on rail and fish-plate.

The resistance of a bonded joint is dependent upon several factors :—

1. The contact resistance of the plugs or rivets, which forms but a small percentage of the whole resistance.

2. The resistance known as the gathering resistance. The current flowing in a long length of rails is at a uniform density across the section, and in such a condition the resistance of the rail is a minimum. At the bonds, however, the current has to flow out of the rail at a reduced area ; this causes an increase in the current density, and consequently an increase in the volts drop. According to Mr. Parshall the gathering at a bond in an 83-lb. rail adds a resistance to the rail equivalent to 3·4 inches of rail length.

3 and 4. The bond resistance is affected by the resistance of the copper strip and by the conductivity of the fish-plate ; the fish-plate acts in parallel with the bond.

The electrically welded joints show a conductivity per equal lengths less than that of the solid rail, as it is not often that the whole of the area is actually welded.

In conclusion, a few notes on the conductivity of continuous conductors may be given.

A subject of great importance, about which a good deal is still to be learnt, is the effect produced on the conductivity by physical changes in the condition of a wire.

. Matthiessen adopted a standard for high conductivity of 1·150822 ohms for annealed copper wire one metre long and weighing one gramme. The resistance to be measured at a temperature of 60° Fahr. This, although adopted as a standard, is not the highest conductivity which can be obtained. Pure electrolytic copper has given after careful deposition (to prevent the formation of the brittle hydride) and annealing at the best temperature, a conductivity several per cent. greater than Matthiessen's standard. The temperature of annealing has a very marked effect upon the conductivity, as was shown in a recent paper by L. Addicks * read before the American Institute of Electrical Engineers.

* *Transactions of the American Institute of Electrical Engineers*, 1903, vol. 20, p. 1593.

He describes tests carried out on a 12 B. and S. hard drawn copper wire. The wire was heated by the passage of currents which varied from zero to the fusing current, which was 220 amperes. After each increase in the strength of the current the wire was allowed to cool and its tensile strength and conductivity ascertained. The results obtained are indicated by curves. The highest conductivity was obtained when the temperature of annealing was such that the wire was barely luminous. The lowering of the conductivity by annealing at the higher temperatures was thought to be due to the absorption of oxygen. This was found to be incorrect: for after the wire had been redrawn and reannealed properly, it again showed a high conductivity. This indicates that the effect is one of a physical nature. It is supposed, and microphotographs of the etched surface of the metal support the view, that when cooling from the high temperatures the metal enters into a semi-crystalline state which has the effect of increasing the resistance.

When the wire is redrawn and reannealed this structure is destroyed and a fine fibre results.

The relation between tensile strength and conductivity is also shown diagrammatically in the paper referred to.

TABLE.

Showing Loss of Energy in an Electrolytic Copper Refinery due to Contact Resistances.

Current, 4,000 *amperes.* *Voltage per tank,* 0·230. *Energy in k.w.,* 0·920.

	Volts.
Drop between the anode rod and the bus-bar ...	0·0270
Drop between the kathode rod and the bus-bar ...	0·0135
Drop between anode rod and anode hanger ...	0·0060
Drop between kathode rod and kathode hanger ...	0·0045
Drop between anode hook and anode	0·0008
Total loss	0·0518

Per cent. total energy lost in contacts, 22·500.

Proceedings of the Thirty-fourth Annual General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 24, 1906—Mr. John Gavey, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on May 17, 1906, were taken as read, and confirmed.

The names of new candidates for election, after having been suspended previous to the meeting in the Library, were taken as read, and the President stated that the present meeting being the last of the session, the candidates would, as usual, be balloted for that evening.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

H. E. M. Kensit.

From the class of Associates to that of Associate Members—

J. R. J. Bowden.
W. H. Evans.
C. H. Hainsworth.
E. T. Parker.
A. Pearson.

From the class of Students to that of Associate Members—

A. N. McIntyre.

Messrs. C. Le Maistre and A. B. Rigby were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Allan R. Connal.
Harry S. Ellis.
R. A. Golding.
Alfred Ingram.
E. C. McKinnon.
Hari C. Mukerji.
Tage G. Nyborg.
S. H. Penning.
N. W. Prangnell.
Edward C. St. John.
Stephen S. Sellick.
J. M. Smith.
L. W. Smith.
Frank C. Taylor.
William Raynes Walton.
George Alfred Wigley.

As Associates.

George Thomas Bullock.
R. F. Cottrell, 2nd Lieut., R.G.A.
Cyril H. Dodd.
Thomas B. Goodyer.
Cuthbert B. Moss-Blundell.

As Students.

Alexander Miller Gray.
Kingsley Douglas McMillan.
Edgar Harold Turtle.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. The Electrician Publishing Co., Ltd., C. H. W. Gerhardi, E. J. Houston, the Royal Commission on the St. Louis Exhibition, 1904, Vickers, Sons & Maxim, Ltd.; to the *Building Fund* from Mr. J. C. Smail; and to the *Benevolent Fund* from Anonymous, per Professor S. P. Thompson, Messrs. R. V. Boyle, M. Heaphy, A. M. Taylor, and J. H. Woolliscroft, to whom the thanks of the meeting were duly accorded.

The Report of Council was then presented as follows :—

REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING OF MAY 24, 1906.

At this the Thirty-fourth Annual General Meeting of the Institution of Electrical Engineers the Council present to the members their Report on the Proceedings of the Institution during the Session 1905–6.

Growth of the Institution.

Since the last and up to this Annual General Meeting inclusive, 505 proposals for election have been considered, and there have been elected 10 Members, 175 Associate Members, 18 Associates, and 254 Students. The names of 2 Members have been restored to the Register, the total addition to the Roll being 459, against which must be set the decrease, owing to deaths, resignations, and erasures.

To the class of Members there have been transferred 33 Associate Members and 4 Associates; to the class of Associate Members there have been transferred 63 Associates and 34 Students.

The change in the roll during the last twelve months is shown in the accompanying table :—

	1905.	1906.
Honorary Members	6	6
Members	994	1,012
Associate Members	1,610	1,805
Associates	1,609	1,419
Students	1,321	1,436
Foreign Members	131	125
Total	5,671	5,803

In the last Report of Council attention was drawn to the new Standing Order passed by the Council that students and candidates who are professionally engaged as Electrical Engineers shall not in future be elected or transferred to the class of Associates, which is reserved strictly for those who, not having been trained as Electrical Engineers, are nevertheless so associated with the application of electricity that the Council consider their admission as Associates would conduce to the interests of the Institution. The effect of the ruling, which is now becoming apparent, is that all candidates for election who are Electrical Engineers must comply strictly with the standard of the qualifications for Membership and Associate Membership as defined in Articles 12 and 13 of the Articles of Association.

Honours have been conferred upon several members of the Institution during the past year. In 1905, Sir A. B. W. Kennedy, a former Member of Council, received the dignity of Knighthood. A similar honour was bestowed upon Sir J. Clifton Robinson, Member. Colonel Sir C. M. Watson, R.E., K.C.M.G., Associate, has had conferre dupon him the Order of Knight Commander of St. Michael and St. George. The Right Hon. Sir Fletcher Moulton, Member, received the honour of Knighthood, and has been appointed a Lord Justice of the Court of Appeal. Sir S. H. C. Hutchinson, Member, Director-General of Telegraphs in India, has also received the rank of Knighthood.

Deceased Members.

Among the members deceased the Council record with regret the names of Mr. W. E. Langdon, Past-President, Mr. Carl von Siemens, a former Vice-President, and Mr. W. Stratford Andrews, both members of the Institution; also that of Sir H. C. Fischer, C.M.G., Associate, and Mr. J. S. Rasmussen, Foreign Member, Local Honorary Secretary and Treasurer for Norway. The full list of members deceased is as follows:—

Members.

W. S. Andrews (*recently resigned*).
J. T. Connolly.
A. C. le Neve Foster.
G. A. Grindle.
A. P. Head.
Geo. Hill.
W. E. Langdon.
E. Macrory, K.C.
P. J. Nelson.
H. M. Peickert.
Carl von Siemens.
J. T. Sprague.
R. F. Yorke.

Associate Members.

A. Battersby.
J. R. Craddock.
J. H. Hamilton.
W. A. Kenneth.
L. J. Langridge.
C. Laszlo.
G. Swetenham.

Associates.

E. F. Blatchford.
G. C. Bompas.
F. C. Danvers.
Sir H. C. Fischer.
G. Jacomb-Hood.
J. Kingston.
H. Marsh.
D. E. Moore.
G. Musket.
C. J. Page.
S. W. G. Tamplin.
A. Anstruther Thomson.

Foreign Members.

J. Frayssinier.
Carl Mulvad.
J. S. Rasmussen.

Students.

B. Foot.
H. Lillywhite.
A. D. Melville.
C. P. Nuttall.

Resignations.

13 Members, 8 Associate Members, 51 Associates, 3 Foreign Members, and 56 Students have resigned since the date of the last Report.

Meetings and Papers.

During the past year there have been 18 Committees at work. 15 General Meetings, 20 Council Meetings, and 114 Committee Meetings have been held.

The subjects dealt with at the General Meetings cover a wide range. The President delivered his Inaugural Address to the members at the opening meeting of the Session, and the following is a list of the papers read at the subsequent meetings :—

1905.

Nov. 23.—"The Application of Electricity in the Royal Gun Factory, Woolwich Arsenal," by Colonel H. C. L. HOLDEN, R.A., F.R.S., Member of Council.

Dec. 7.—"The City of London Works of the Charing Cross, West End, and City Electricity Supply Co., Ltd.," by W. H. PATCHELL, Vice-President.

1906.

Jan. 25.—"Technical Considerations in Electric Railway Engineering," by F. W. CARTER, M.A., Associate Member.

Feb. 22.—"Crane Motors and Controllers," by C. W. HILL, Member.

Mar. 8.—"A New Single-phase Commutator Motor," by V. A. FYNN, Member.

Mar. 22.—"Electrical Equipment of the Aberdare Collieries of the Powell Duffryn Company," by C. P. SPARKS, Member of Council.

In conjunction with this paper the two following, read at Manchester and Newcastle respectively, were discussed :—

"Electric Winding Considered Practically and Commercially," by W. C. MOUNTAIN, Member, and "Electric Winding Considered Practically and Commercially," by G. HOOGHWINKEL, Member.

April 26.—"Long Flame Arc Lamps," by L. ANDREWS, Member.

May 17.—"Notes on Overhead Equipment of Tramways," by R. N. TWEEDY, Associate Member, and H. DUDGEON. Discussion on paper read at Birmingham.

In addition to the above-mentioned papers the following have been accepted as "Original Communications" and printed in the Journal :—

"On the Testing of Cast Iron and other Materials by the Ewing Permeability Bridge," by A. CAMPBELL, Associate Member.

"New Iron Cored Instruments for Alternate-Current Working," by Dr. W. E. SUMPNER, Member.

"Note on the Use of the Bolometer as a Detector of Electric Waves," by Lieut. TISSOT.

Local Sections.

The several Local Sections of the Institution continue to carry on their work with energy and success. During the Session 43 meetings have been held, as follows :—

At Birmingham 7, at Dublin 7, at Glasgow 7, at Leeds 6, at Manchester 10, and at Newcastle 6,

The following papers have been read and discussed at Local Section Meetings, and those marked with an asterisk have been accepted for publication :—

BIRMINGHAM.

1905.

Nov. 16.—Chairman's Address, by Professor R. THRELFALL, F.R.S., Member.

*Dec. 13.—"Two New Electrolytic Meters," by S. H. HOLDEN, Member.

1906.

*Jan. 17.—"A New Method of Automatic Boosting," by M. J. E. TILNEY, Associate Member.

*Feb. 14.—"Notes on Overhead Equipment of Tramways," by R. N. TWEEDY, Associate Member, and H. DUDGEON.

*April 25.—"The Testing of Transformers and Transformer Iron," by Dr. D. K. MORRIS, Associate Member, and G. A. LISTER, Associate Member.

* „ „ —"A Simple Method of Measuring Sparking Voltages," by E. A. WATSON, Student.

DUBLIN.

1905.

*Nov. 9.—Chairman's Address, by P. S. SHEARDOWN, Member.

Dec. 14.—"Some Points Relating to Storage Batteries and Boosters," by L. BROEKMAN.

1906.

*Jan. 18.—"Electric Hoisting and Conveying Machinery," by JOHN RITCHIE.

Feb. 8.—"Some Notes on Motor Driving," by W. J. BELSEY, Associate Member.

Mar. 8.—"Gas Producer Plant for Electric Generating Stations," by W. J. U. SOWTER, Associate Member.

April 5.—"Coal Testing," by JOHN HOLLIDAY.

May 10.—"In how small a Town is it possible to operate successfully an Electric Lighting Plant ?" by R. B. FORSTER, Associate Member.

GLASGOW.

1905.

*Nov. 14.—Chairman's Address, by J. M. M. MUNRO, Member.

*Dec. 12.—"Recent Advances in Wireless Telegraphy," by Dr. J. ERSKINE-MURRAY, Member.

1906.

Jan. 9.—"The Maintenance of Underground Mains," by G. BLACK, Associate Member.

*Mar. 13.—"The Internal Energy of Elements," by F. SODDY.

April 10.—"Notes on Booster Developments," by A. H. KELSALL, Associate Member.

May 8.—"Observations on the Mercury Arc and Some Resultant Problems in Photometry," by C. O. BASTIAN, Member.

LEEDS.

1905.

*Oct. 25.—Chairman's Address, by A. B. MOUNTAIN, Member.

„ „ —"Notes on Alternate Current Induction Motors," by T. H. CHURTON, Associate.

Nov. 23.—"Destructors and their Bye-Products," by F. L. WATSON.

*Dec. 13.—"Secondary Cells, their Deterioration and the Causes," by G. D. A. PARR, Member.

1906.

*Jan. 18.—"The Rectification of Alternating Currents," by P. ROSLING, Member.

*Feb. 15.—"Waste in Incandescent Lighting, and Some Suggested Remedies," by G. WILKINSON, Member.

„ „ —"The Cost of Electricity per Unit from Private Electrical Plants," by W. HARTNELL, Member.

MANCHESTER.

1905.

*Nov. 17.—Chairman's Address, by S. L. PEARCE, Member.

„ 28.—"Street Cable Systems," by S. J. WATSON, Member.

„ „ —"The Calculation of Electric Feeders," by W. G. RHODES, D.Sc., Member.

*Dec. 12.—"Street Lighting," by H. T. HARRISON, Member.

1906.

*Jan. 16.—"Electric Winding Considered Practically and Commercially," by W. C. MOUNTAIN, Member.

„ 30.—"Gas Engines as Applied to Electric Driving," by J. ATKINSON.

*Feb. 13.—"Idle Currents," by M. B. FIELD, Member.

*Feb. 27.—"Single-phase Railway Motors and Methods of Controlling Them," by T. H. SCHOEPF, Member.

*Mar. 13.—"Economic Considerations in the Employment of Storage Batteries," by J. R. SALTER, Member.

*Mar. 27.—"Investigation into the Periodic Variations in the Magnetic Field of a Three-phase Generator by Means of the Oscillograph," by G. W. WORRALL and T. F. WALL, Student.

*April 10.—"Lifts and Hoists," by H. C. CREWS, Member.

NEWCASTLE.

1905.

*Nov. 20.—Chairman's Address, by W. M. THORNTON, D.Sc., Member.

Dec. 11.—"The Commercial Testing of Small Motors up to 15 B.H.P.," by T. CARTER, Associate Member.

1906.

*Jan. 15.—"A Reversible Booster and its Running," by C. TURNBULL, Associate Member.

Feb. 5.—"Electric Wiring of Small Buildings during Course of Erection," by R. ROBSON, Associate Member.

„ „ —"Electric Ignition for Motor Cars," by F. LITTLE, Associate Member.

*Feb. 26.—"The Distribution of Magnetic Induction and Hysteresis Loss in Armatures," by W. M. THORNTON, D.Sc., Member.

*Mar. 12.—"Electric Winding Considered Practically and Commercially," by G. HOOGHWINKEL, Member.

May 14.—"The Regulation of the Pressure of Discharge of Lighting Batteries," by E. P. HOLLIS, Student, and E. R. ALEXANDER, Student.

The Council desire to place on record their appreciation of the services of the Chairmen and Committees, and of the Honorary Secretaries who have organised the meetings and promoted the interests of the Institution in their several districts.

At the Annual Dinners and at the social functions in the Local Centres there has been a large attendance on the part of members and guests. The President and several Members of Council were present on various occasions.

The Cape Town Local Section, during the year ending March 31, 1906, has held 7 General Meetings for the discussion of papers. Although that Local Section cannot point to any original communications by its members, certain of the home papers have been selected by the Committee, upon which organised discussions have been raised, and by this means much useful and interesting material has been brought before the members of the South African Section of the Institution.

Salomons Scholarship.

The Council has awarded one Salomons Scholarship, value £50, to :—

Mr. R. G. Jakeman, of University College, London.

David Hughes Scholarship.

Two David Hughes Scholarships, value £50 each, have also been awarded to :—

Mr. A. Kinnes, of the Central Technical College.
Mr. G. F. O'Dell, of King's College.

Annual Premiums.

The Council have awarded the following premiums for papers and communications :—

The Institution Premium, value £25,

to Mr. V. A. Fynn, for his paper "A New Single-phase Commutator Motor."

The Paris Electrical Exhibition Premium, value for this year £20,

to Professor A. Schwartz and Mr. W. H. N. James, for their paper "Low-Tension Thermal Cut-Outs."

An Extra Premium, value £10,

to Mr. Haydn T. Harrison, for his paper on "Street Lighting."

An Extra Premium, value £10,

to Mr. W. J. A. London, for his paper on "The Mechanical Construction of Steam Turbines."

An Extra Premium, value £10,

to Dr. D. K. Morris and Mr. G. A. Lister, for their paper on "The Eddy Current Brake for Testing Motors."

An Extra Premium, value £10,

to Mr. R. N. Tweedy and Mr. H. Dudgeon, for their paper on "Notes on Overhead Equipment of Tramways."

An Original Communication Premium, value £10,

to Dr. W. E. Sumpner, for his communication "New Iron Cored Instruments for Alternate-Current Working."

The Fahie Premium.

Not awarded this year.

Students' Premiums.

The First Students' Premium, value £10, to Mr. A. G. Ellis, for his paper "Steam Turbine Dynamos."

The Second Students' Premium, value £8, to Mr. H. W. Taylor, for his paper "Some Notes of Single-phase Railways."

The Third Students' Premium, value £5, to Messrs. F. C. Prentice and J. S. Westerdale, for their paper "The Efficiency of Lamp Globes."

An Extra Premium, value £5, to Mr. W. Browning, for his paper "Notes on Electrical Conductivity."

Papers which were received too late for consideration in making the awards of premiums in 1905 have been taken into account this year. Papers other than those of the Students' Section, which were not in type up to the end of April, 1906, have been reserved for consideration in 1907. In accordance with precedent the Council, in awarding premiums, have not taken into account papers contributed by present Members of Council.

Students' Section.

Meetings of the Students' Section have been held in London at which papers have been read and discussed. By the kind permission of the authorities concerned, visits to a number of works and other places of electrical interest were made during the Session. At Easter-time the Students' Committee successfully organised an excursion to Manchester, where many of the leading electrical firms also granted facilities for the inspection of their works.

The Council desire to express their best thanks to the respective managers for their kindness in throwing open to the students of the Institution the works and laboratories under their control.

The Manchester Branch of the Students' Section has also held meetings throughout the Session for the reading and discussion of papers, and took part with their colleagues from London in the visits paid to works in Manchester during the Easter holidays.

The Glasgow Local Section announces that a Students' Section has now been formed at Glasgow. Arrangements were only matured at the latter part of the Session, and a preliminary meeting for the election of office-bearers has been held. The Committee elected Professor Magnus Maclean as Chairman, and are making arrangements for papers and visits during the coming Session. It is hoped that the formation of this Section will be the means of causing a large increase in the number of Students in the Scottish Section.

The Annual Dinner of the Students' Section took place at the Holborn Restaurant on Thursday, February 15, 1906, and was well attended. The Chairman of the Students' Section, Mr. A. G. Ellis, occupied the chair, and the guests included the President, Mr. John Gavey, C.B., and a number of Members of Council.

Other Work of the Session.

In addition to the routine work of the Session, the important work of revising the Wiring Rules of the Institution has been almost completed by the Committee appointed for that purpose, and it is hoped to publish the new edition before the end of the current year.

The Council have also directed their attention to the terms of the London Building Acts Amendment Bill, 1905, and, in consideration of the probability that the restrictions in the Bill would prejudicially affect buildings of electrical companies and undertakings, a petition against the Bill was drawn up and presented to Parliament.

The Workmen's Compensation Bill, 1906, also received attention. It was thought that the terms of the Bill were detrimental to the interests of certain branches of the Electrical Industry, and accordingly a letter was addressed to the Home Secretary petitioning that the objectionable clause might be altered.

At the request of the Committee of Organisation of the Electrical Exhibition held at Olympia in the autumn of 1905, the Council agreed to extend the patronage of the Institution to the Exhibition. A series of Evening Lectures was arranged by the Council to be given at the Exhibition, and thanks are due to the following Members of the Council, and others, who gave their services as lecturers :—Colonel R. E. Crompton, C.B., Mr. W. M. Mordey, Mr. W. Duddell, Mr. S. Z. de Ferranti, Mr. F. Gill, Mr. F. Bailey, Mr. J. Dowsing, and Mr. A. Martin.

Mr. J. E. Kingsbury and Mr. W. H. Patchell, Vice-Presidents, and Mr. F. Gill, Member of Council, were members of the Organising Committee of the Exhibition.

In pursuance of a Resolution passed by the Chamber of Delegates at the Electrical Congress at St. Louis, the Council have to report that steps have been taken to secure the co-operation of the Technical Societies of the world by the appointment of a representative Commission to consider the question of the Standardising of the Nomenclature and Ratings of Electrical Apparatus and Machinery. An Executive Committee has been formed by the Council, with instructions to consider and report upon a scheme for the constitution of such an International Commission, and a draught scheme has now been submitted for approval to the leading Electrical Associations of all countries. The first meeting of Delegates of these Associations will be convened at an early date.

It will also be remembered that at the same Congress it was resolved that an endeavour should be made to summon an International Conference to consider and determine the question of Electrical Standards, Units, and Nomenclature. The question has been considered by H.M. Government, and it is hoped that the Conference will assemble within a reasonable period of time.

Appointment of Representatives.

In 1903 a General Committee was appointed by the Institution of Civil Engineers for the Consideration of the best Method for the proper Education and Training of Engineers. In response to an invitation to

appoint a representative to act on that Committee, the Council of the Institution of Electrical Engineers nominated Mr. R. Kaye Gray, the President of that year.

The Council further appointed an Advisory Committee on the Education of Electrical Engineers to assist them in formulating proposals to submit through their representative to the General Committee. This Advisory Committee consisted of the following members :—

Robert Kaye Gray (*Chairman*).

Professor W. E. Ayrton.	A. Siemens.
W. A. Chamen.	G. Stoney.
Professor J. D. Cormack (*Reporter*).	J. Swinburne.
	Professor S. P. Thompson.
E. W. Cowan.	Professor W. E. Thrift.
Colonel R. E. Crompton, C.B.	J. C. Vaudrey.
H. Dickinson.	Major-General C. E. Webber, C.B. (the late).
W. H. Patchell.	

The General Committee have now completed their work, and their Report has been presented to and adopted by the Council of the Institution of Civil Engineers, and copies have also been presented to the Council of this Institution. In issuing it, the Council of the Institution of Civil Engineers have expressed, through the Chairman of the Committee, Sir William White, K.C.B., to this Institution their warm thanks for the assistance which the General Committee received in the prosecution of the inquiry, and especially for the co-operation of its representative, Mr. Gray. Acknowledgments are also due to the above-mentioned members of the Advisory Committee of the Council for the great assistance rendered by them.

As it appeared desirable that the recommendations contained in the Report, in view of their importance to the Engineering Profession, should be brought to the attention of the members of this Institution, the Council further have decided that, with the permission of the Institution of Civil Engineers, the Report should be reprinted as an addendum to the Annual Report of the Council. The reprint of the Report will be found on page 415.

An invitation was received in January from the American Philosophical Society of Philadelphia to send a representative to attend the celebrations in Philadelphia in April, 1906, upon the occasion of the bicentenary of the birth of Benjamin Franklin. Sir William H. Preece, K.C.B., Past President, was appointed to represent the Institution on the occasion, but was unfortunately prevented from undertaking the journey. An illuminated Address of Greeting which had been prepared was sent to Professor Elihu Thomson, Hon. Member, and was presented by him to the American Philosophical Society in honour of the event.

The Council was invited in the early part of the year by the Home Office to nominate a representative to advise the Department in preparing a code of Regulations for the generation and use of Electricity in Factories and Workshops. In this matter Mr. W. H. Patchell, Vice-President, was appointed to assist the Home Office as requested.

Mr. W. H. Patchell was also appointed to serve on the Organising Committee of the International Mining Conference to be held in London in June, 1906.

Invitation to Kindred Institutions in 1906.

The Council have considered it desirable that the Institution should endeavour in some measure to return the courtesies received in former years from the Electrical Institutions in Europe and America. As a preliminary step inquiries were made in the various Local Centres as to whether the Local Committees would be able to lend support to the scheme and to co-operate in providing a welcome to the guests, and the replies showed that opinion was unanimously in favour of the proposal. Invitations were accordingly issued to and have been accepted by the following Associations :—

The American Institute of Electrical Engineers.
The Canadian Electrical Association.
The Société Internationale des Electriciens.
The Elektrotechnischer Verein.
The Verband Deutscher Elektrotechniker.
The Associazione Elettrotecnica Italiana.
The Schweizerischer Elektrotechnischer Verein.

A programme for the entertainment of the guests is in active preparation, and the plan, as far as arranged, will consist of a three days' stay in London. The proceedings in London will begin on Monday, June 25th, after which a tour of about ten days will be undertaken through those centres in Great Britain in which Local Sections are established.

Presentation of His Portrait to Mr. Robert Kaye Gray, Past President.

In grateful recollection of the exceptional services rendered to the Institution by Mr. Robert Kaye Gray during his tenure of office as President from April, 1904, to November, 1905, a number of the members expressed the wish that he would sit for his portrait, and that on its completion they might be allowed to present it to him. Mr. Gray having assented to the proposition, a committee was formed, of which Sir Joseph W. Swan, Past President, was the Chairman, and Mr. W. H. Patchell, Vice-President, acted as Honorary Secretary. Miss Beatrice Bright, daughter of the late Sir Charles T. Bright, Past President, was invited to undertake the work of painting the portrait, and the presentation of it to Mr. Gray took place with due ceremony at the General Meeting of April 5th, at the Institution of Civil Engineers. A replica of the excellent portrait, also painted by Miss Bright, was presented by the members at the same time to the Institution, and this now hangs in the Library.

Annual Conversazione.

The Annual Conversazione was held on June 29, 1905, at the Natural History Museum, and was largely attended. The guests were received by Mr. Alexander Siemens, the President then in office, and Mrs. Siemens, and by Mr. J. Gavey, C.B., the President-elect, and Mrs. Gavey.

Annual Dinner.

The Annual Dinner was held at the Hotel Cecil on December 8, 1905, the company numbering 384.

The President, Mr. John Gavey, C.B., occupied the chair, and many distinguished guests attended.

Building Fund.

The Building Fund, which at the commencement of the year 1904 stood at £19,398 12s. 4d., amounted on December 31, 1905, to £19,856 17s. 8d. The property on the site is fully let on advantageous terms, and an increased revenue may confidently be anticipated during the current financial year. The term of five years during which many of the members agreed to contribute a regular yearly amount has now expired, but it is hoped that they will renew their subscriptions and continue to contribute annually as hitherto.

Benevolent Fund.

With regard to this Fund, the Council have the pleasure to report that the Organising Committee of the Electrical Exhibition at Olympia allocated a portion of the profits of that enterprise to the Benevolent Fund of the Institution, and in due course the Committee handed to the Council a donation to the Fund of £350. The first announcement of the Committee's intention was made at the Annual Dinner by the Chairman of the Committee, Mr. E. Cunliffe Owen, C.M.G. The Electrical Engineers' Ball Committee have given a donation of £25 to the Fund from the surplus at their disposal after meeting the expenses of this year's ball. The best thanks of the Council are due to these and to the other donors and subscribers to the Fund.

The regular contributors to the Fund amongst the members of the Institution have somewhat increased in number, but it is still a matter of regret that the number of these is comparatively small. The capital account of the Fund on December 31, 1905, stood at £2,021, as compared with £1,849 at the end of 1904. This amount does not include the two donations above referred to, which have since been added to the Fund. Two grants in aid were made during the year under the rules of the Committee.

Wilde Benevolent Fund.

No grant has been made from this Fund during the past year.

Annual Accounts.

The Annual Statement of Accounts for 1905, duly audited, is appended to the Report, and the Council are pleased to note that the financial position is again satisfactory. The Income and Expenditure compare with 1904 as follows :—

	Income.		Expenditure.		Carried to General Fund.
1904	£10,075 17 4	...	£7,950 1 5	...	£2,125 15 11
1905	£10,369 0 8	...	£7,066 5 6	...	£3,302 15 2

The Entrance Fees for the year, which are not treated as Income, amounted to £569 3s., and this sum has been carried to Capital Account.

Library.

The work of reorganising the Library is steadily progressing, and special grants have been made by the Council in aid of the work.

A sum of money has also been voted to be expended on the acquirement of writing tables and other articles of furniture which will greatly add to the comfort and convenience of the members and visitors who desire to consult the books and periodicals.

A safe has been purchased, in which the more valuable works and rare early editions of books are stored. A small Committee, consisting of Dr. S. P. Thompson, F.R.S., Past President, Mr. W. Duddell, and Mr. T. Mather, F.R.S., is devoting much time and labour to the work of compiling lists of the works which are required to bring the Library up to date, and the thanks of the Council are due to this Committee for the valuable assistance which they are rendering. In this connection appeals which have been sent out to members who are authors of works of Electrical interest to present copies of their books have been generously responded to, upwards of 130 new books having been presented to the Library by members in the last few months.

An Arc Lantern and a special Circuit for lecture experiments has been installed in the Library for use at meetings of the Students' Section and of other Societies who avail themselves of the room for purposes of reading and discussion of papers.

The accessions to the Library during the period from May 31, 1905, to the date of this Annual General Meeting numbered 405, nearly all of which have been presented by the authors or publishers.

The supply of Specifications of Electrical Patents and of Abridgments of Specifications relating to Electricity and Magnetism is continued by the kindness of H.M. Commissioners of Patents, and the arrangement is still in force whereby the Specifications of all Electrical Patents published during any week are placed on the Library table on the following Monday morning.

The periodicals or printed Proceedings of other societies received regularly are, with some additions, the same as last year.

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

BRITISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society, Proceedings.
Engineering Association of New South Wales, Proceedings.
Faraday Society, Transactions.
Greenwich Magnetical and Meteorological Observations.
Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland, Transactions.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
King's College Calendar.
Liverpool Engineering Society, Proceedings.
Municipal Electrical Association, Proceedings.
National Physical Laboratory Report.
North-East Coast Institution of Engineers and Shipbuilders, Transactions.
North of England Institute of Mining and Mechanical Engineers, Transactions.
Physical Society, Proceedings.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Proceedings.
Royal Scottish Society of Arts, Transactions and Journal
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
Surveyors' Institution, Transactions.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings.
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Mechanical Engineers, Transactions.
Bureau of Standards, Washington, Bulletin.
Canadian Society of Civil Engineers, Transactions.
Engineers' Club of Philadelphia, Proceedings.

Franklin Institute, Journal.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Electro-Technique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DANISH.

Tekniske Forening, Tidsskrift.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Société Française de Physique, Bulletin des Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.
Physikalische Technische Reichsanstalt, Abhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Magazine.
Electrical Review.
Electrical Times.

Electrician.
Electricity.
Engineer.
Engineering.
Engineering Times.
English Mechanic and World of Science.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
Invention.
Iron and Coal Trades Review.
Light Railway and Tramway Journal.
Mechanical Engineer.
Nature.
Page's Weekly.
Philosophical Magazine.

AMERICAN.

American Electrician.
Electric Journal
Electric Railway Review.
Electrical Review.
Electrical World and Electrical Engineer.
Engineering News.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Technology Quarterly.
Western Electrician.

AUSTRIAN.

Elektrotechnik und Maschinenbau.

DUTCH.

De Ingenieur.

FRENCH.

L'Éclairage Électrique.
L'Electricien.
L'Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Fortschritte der Elektrotechnik.
Glückauf.
Technische Literatur.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

L'Elettricità.
Giornale del Genio Civile.
Il Nuovo Cimento.

SPANISH.

La Ingenieria.

The Institution of

STATEMENT OF INCOME AND
ENDING 31st

Dr.

EXPENDITURE.

	£	s.	d.	£	s.	d.
To MANAGEMENT :—						
Salaries	1,454	18	0			
Retiring Allowance	300	0	0			
Accountants' Fees	15	15	0			
Addressing	63	3	2			
Printing and Stationery	354	0	4			
Postage	753	9	3			
Telephone	26	10	0			
Travelling	15	13	11			
				2,983	9	8
,, RENT, INSURANCE, LIGHTING, AND FIRING				675	5	6
,, PUBLICATIONS :—						
Journal	1,306	18	0			
"Science Abstracts"—						
Disbursements £1,937 13 1						
Less Receipts 1,261 7 7						
	676	5	6			
				1,983	3	6
,, MEETINGS :—						
Advance Proofs, Refreshments, &c.	145	12	4			
Reporting	64	1	0			
				209	13	4
,, LOCAL SECTIONS				544	18	5
,, PREMIUMS				119	5	10
,, LAW CHARGES				52	4	10
,, MISCELLANEOUS EXPENSES				90	10	10
,, CONVERSAZIONE				269	19	8
,, ANNUAL DINNER				54	13	7
,, DEPRECIATION :—						
Library (5 %)	64	12	0			
Furniture (5 %)	18	8	4			
				83	0	4
,, BALANCE carried to General Fund, being excess of Income over Expenditure				3,302	15	2
				£10,369	0	8

EXPENDITURE FOR THE YEAR DECEMBER, 1905.

Cr.

INCOME.

	£ s. d.	£ s. d.
By Subscriptions for 1905 :—		
Received	8,733 17 6	
Outstanding (Estimated Value)	750 0 0	
		9,483 17 6
,, Dividends on Investments :—		
Life Compositions	£172 12 1	
General Fund	221 12 6	
		394 4 7
,, Interest on Cash on Deposit		24 14 0
,, Journal :—		
Sales	166 3 4	
Advertisements	284 0 0	
		450 3 4
,, Wiring Rules		10 14 9
,, Model General Conditions for Contracts		5 6 6
		£10,369 0 8

Dr.

	£	s.	d.
To Amount (as per last Account)	5,536	18	0
,, Life Compositions received during 1905	59	10	0
	5,596	8	0
Less Deficit on Redemption of £400 New South Wales 4% Bonds at par	14	15	0
	£5,581	13	0

Cr.

				£	s.	d.
By Investments (at cost) :—						
£318	0	0	Cape of Good Hope 4 % Consolidated Stock	306	0	0
1,679	19	5	India 3½ % Stock	1,776	5	0
120	0	0	South-Eastern Railway 5 % Debenture Stock	204	16	6
355	5	10	Canada 3 % Stock	352	13	6
289	17	4	Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10
6	0	0	East Indian Railway Class "C" Annuity ...	185	1	9
87	0	0	Great Eastern Railway 4 % Consolidated Preference Stock	130	15	2
175	0	0	Great Eastern Railway 4 % Debenture Stock	251	5	5
5	6	4	Great Indian Peninsula Railway "B" Annuity	133	17	6
143	0	0	Southwark and Vauxhall Water Co. 4 % "A." Debenture Stock	207	17	9
520	0	0	Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3
200	0	0	Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0
29	0	0	Madras Railway 5 % Stock	44	9	4
60	0	0	South Indian Railway 4½ % Debenture Stock	88	1	4
30	0	0	Burma Railway Co.'s Stock	30	12	3
40	0	0	East Indian Railway 4½ % Debenture Stock ...	57	3	7
400	0	0	Natal Zululand Railways 3 % Debentures ...	351	1	0
350	0	0	New Zealand 3½ % Inscribed Stock	345	12	10
				£5,555	12	0
Balance uninvested carried to Balance Sheet				26	1	0
				£5,581	13	0

Dr.

	£	s.	d.
To Amount (as per last Account)	19,398	12	4
,, Revenue from Tothill Street Property in 1905	355	14	4
,, Subscriptions received during 1905	93	16	0
,, Surplus from Vellum Diplomas	8	15	0
	£19,856	17	8

Cr.

	£	s.	d.
By Building Site (as per last Account)	19,260	17	1
„ Balance carried to Balance Sheet	596	0	7
	£19,856	17	8

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1905...	100	0	0
„ Balance carried to Balance Sheet	40	1	2
	£140	1	2

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount paid to Scholars in 1905...	75	0	0
„ Balance carried to Balance Sheet	54	9	9
	£129	9	9

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,500	0	0
	£1,500	0	0

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount invested in P.O. Savings Bank	253	13	5
„ „ uninvested carried to Balance Sheet	2	1	2
	£255	14	7

405

FUND CAPITAL.

	Cr. £	s.	d.
By Investments (at cost) :—			
£1,500 New South Wales 3½ % Stock	1,556	5	9
500 Cape of Good Hope 3½ % Stock	570	13	6
	£2,126	19	3

FUND INCOME.

	Cr. £	s.	d.
By Balance (as per last Account)	70	5	7
,, Dividends received in 1905	69	15	7
	£140	1	2

SHIP FUND CAPITAL.

	Cr. £	s.	d.
By Investment (at cost) :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
,, Balance uninvested carried to Balance Sheet	1	5	0
	£2,000	0	0

SHIP FUND INCOME.

	Cr. £	s.	d.
By Balance (as per last Account)	68	7	3
,, Dividends received in 1905	61	2	6
	£129	9	9

FUND CAPITAL.

	Cr. £	s.	d.
By Investment (at cost):—£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
,, Amount invested in P.O. Savings Bank	6	3	9
	£1,500	0	0

FUND INCOME.

	Cr. £	s.	d.
By Amount (as per last Account)	206	7	10
,, Dividends received in 1905	43	12	4
,, Interest do. do.	5	14	5
	£255	14	7

BALANCE SHEET,

Dr.

LIABILITIES.

					£	s.	d.
To Sundry Creditors					736	18	5
„ Local Sections :—							
Due to Hon. Sec. Birmingham Section ...	1	19	6				
do. do. Dublin do. ...	16	4	7				
do. do. Manchester do. ...	50	6	5				
					68	10	6
„ Subscriptions received in advance :—							
On Account of 1906	80	11	6				
do. do. 1907	2	8	6				
					83	0	0
„ Salomons Scholarship Fund Income					40	1	2
„ David Hughes Scholarship Fund :—							
Capital uninvested	1	5	0				
Income	54	9	9				
					55	14	9
„ Wilde Benevolent Fund Income					2	1	2
„ Building Fund					596	0	7
„ Life Compositions uninvested					26	1	0
„ Entrance Fee Fund :—							
As per last Balance Sheet	2,729	0	6				
Received during 1905	569	3	0				
					3,298	3	6
„ General Fund :—							
As per last Balance Sheet	3,902	0	6				
Add Excess of Income over Expenditure for 1905	3,302	15	2				
Surplus of Actual Receipts in 1905 over Estimated Value of Outstanding Subscriptions in last Accounts	218	6	6				
					7,423	2	2
					£12,329	13	3

G. C. LLOYD.
Secretary.

We beg to report that we have examined the above Balance Sheet and have inspected the Bankers' Certificates of Investments and have seen the correct, and the Balance Sheet is properly drawn up so as to exhibit a true its books. We hereby certify that all our requirements as Auditors have

ALLEN, BIGGS & CO.,
Chartered Accountants,
38 PARLIAMENT STREET, S.W.

6th April, 1906.

31st DECEMBER, 1905. 407.

Cr.

ASSETS.

				£	s.	d.
By Cash :—At Bankers'	675	18	2			
Petty Cash	47	1	5			
				722	19	7
„ Local Sections :—						
Cash in hands of Hon. Sec. Glasgow Section	10	7	0			
do. do. do. Leeds Section ...	2	16	2			
do. do. do. Newcastle Section	8	5	9			
				21	8	11
„ Investments (at cost) :—						
£1,418 8 0 Midland Railway 2½% Consolidated Perpetual Preference Stock	£1,200	0	0			
918 3 2 India 3½ % Stock	973	17	10			
52 13 8 Great Indian Peninsula Railway "B" Annuity	1,239	17	9			
721 0 0 Madras Railway 5% Stock ...	1,114	14	0			
410 0 0 East Indian Railway 4½ % Debenture Stock...	586	1	7			
623 0 0 Great Western Railway 5 % Preference Stock	999	18	1			
As per last Balance Sheet ...	6,114	9	3			
Investments during 1905 :—						
2,200 0 0 Natal Zululand Railways 3 % Debentures	1,919	11	0			
650 0 0 New Zealand 3½ % Inscribed Stock	641	18	2			
				8,675	18	5
„ Subscriptions outstanding (Estimated Value)				750	0	0
„ Sundry Debtors				574	16	11
„ Furniture :—						
As per last Balance Sheet	352	17	2			
Additions during 1905	15	10	0			
	368	7	2			
Less Depreciation (5 %)	18	8	4			
				349	18	10
„ Books, Pictures, &c., other than the Ronalds Library :—						
As per last Balance Sheet	1,246	16	10			
Additions during 1905	45	2	10			
	1,291	19	8			
Less Depreciation (5 %)	64	12	0			
				1,227	7	8
„ Stock of Vellum Diploma Forms				7	2	11
				£12,329	13	3

Statements of Account with the Books and Vouchers of the Institution. We Title Deeds of the Tothill Street Property. In our opinion the Statements are and correct view of the state of the affairs of the Institution as shown by been complied with.

F. C. DANVERS }
SIDNEY SHARP } *Honorary Auditors.*

The PRESIDENT: I now beg leave to move, "That the Annual Report of the Council as presented be received and adopted, and that it be printed in the *Journal* of the Proceedings of the Institution."

In accordance with the usual practice I may perhaps be allowed to refer to one or two points of interest to the Members. You will no doubt have observed that the membership is thoroughly satisfactory; we have increased from 5,671 to 5,803 In looking at those figures one point will no doubt have struck you, and that is that the Associates have diminished in number from 1,609 to 1,419. Under the old organisation the class of Associates was a rather indefinite one; it opened the door to a large number of people who were not engineers and who were not electricians, and who in some cases had an indefinite connection with the profession. In the paragraph which follows the table it will be observed that it was decided last year that the entrance to the grade of Associates should be limited, and that under no circumstances should those who claimed to be trained electrical engineers be admitted as Associates; they must enter either as Associate Members or as Members, if qualified; under this rule the number of Associates is likely to diminish, and such persons who have hitherto entered under that classification, and now under the new regulations are not entitled to do so, will cease to enter in the future. Therefore the class may be considered as a diminishing class as compared with the numbers who came under that heading in the past. Whilst on this point I should like to refer to a difficulty which the Council frequently experiences in considering the election of Members of the Institution. It receives from would-be candidates forms which are signed by Members and Associate Members of the Institution, which signatures are supposed to indicate recommendations to the Council for the election of candidates. In many cases these signatures have been appended to the application forms without much consideration, and we have had cases in which, when the qualifications of the candidate appeared to be scarcely up to the mark of the Institution's requirements, the proposers and seconders or the supporters have admitted that they knew very little of the candidate's qualifications. Now, the Council has a very important duty to perform in electing candidates to the membership of the Institution. It endeavours to carry out that duty with the utmost care, and with the ultimate object of raising the status of the Institution to as high a pitch as is possible, but it cannot carry out this duty in a thoroughly satisfactory manner unless it is fully supported by its Members, and that support can only be rendered by giving thoroughly straightforward and honest recommendations in relation to the candidates they support.

Next as to the growth of the Institution at large, the Students' Sections are growing very rapidly, and I think that is a very happy augury for its welfare, because it must be borne in mind that the present students are the future Members, the future Council, the future Presidents of the Institution. One point in the Report I may perhaps refer to briefly, and that is the question of the future training and education of engineers. That, I need not say, is a question of the very highest importance, and you will observe that your Council have

taken a very active share in drawing up the Regulations which have been issued by the Institution of Civil Engineers as to the future training of Engineers, and you will find a reprint of the general recommendations following this Report.

In the next place it will be of interest to the Members to know that, in connection with the invitation which the Institution has issued to those countries who in past years have extended a very warm hospitality to our own Members who have gone either across the Channel or across the Atlantic to witness the great works that have been carried out by kindred Institutions—it will be very satisfactory to know that our own invitations have been cordially accepted, and that we expect towards the end of June to receive visits from our friends from Germany, France, Switzerland, Italy, the United States, and Canada. We altogether expect from about 210 to 220 guests, and we hope that the Members of the Institution will join heartily in extending the same hospitality to our friends as we have received from them in the past. With these few remarks I beg to move, "That the Report of the Council, as presented, be received and adopted, and that it be printed in the *Journal* of the Proceedings of the Institution."

Mr. F. GILL seconded the motion, which was then put to the meeting and carried unanimously.

The PRESIDENT: The next resolution I have to propose is, "That the Statement of Accounts and Balance Sheet for the year ending December 31, 1905, as presented, and of which copies have been sent to the Members, be received and adopted.'

Mr. R. HAMMOND (Honorary Treasurer): It affords me very great pleasure to second the motion for the adoption of the Statement of Accounts and Balance Sheet. I think we are to be congratulated on our financial position. We had an income during the past year on account of subscriptions of £9,483. We are slightly better off in the matter of income than we were with the previous year's accounts, the difference being £305. With regard to our spendings, we of course find that from time to time it is necessary somewhat to increase our expenditure. We have not hesitated to increase our expenditure in connection with our Local Sections, and I think we are all agreed that the strengthening of our Local Sections is a very important work of the Council. Then with regard to our publications, we feel that those Members who take the trouble to write papers of importance, for reading either in London or in the provinces, should be thoroughly encouraged by their publication. The result is that our increased expenditure has amounted to £364, whereas our increased receipts only amounted to £305, leaving a deficit, as far as that is concerned, of £59. Of course we are all very desirous that every year we should carry forward a little more money than we did the year before, and the Honorary Treasurer shares that feeling to the full. Therefore, being £59, as it were, behindhand, we have had to look round to see whether in certain directions we could not reduce our expenditure, that is to say, whether, having increased our expenditure on some items, there were not some decreases which could be set against that increase. Accordingly

you will notice that we have decreased our expenditure in the direction of *Science Abstracts,* for instance. We have not had a St. Louis Conference, and we therefore have a decrease to the extent of the grant that was made in connection with the delegation to that Conference, with the final result that the accounts for 1905 show a balance to the good compared with those of 1904 of a matter of £1,176. I think it would be interesting if I also give the Members an idea of the extent of our possessions at the present moment. Our Building Fund amounts to £19,856, and I think we may all say that the step which was sanctioned by the Institution some few years ago, of investing that money in a site in Tothill Street, has been a step which we have every reason to be glad of. The property is increasing in value, and altogether looks like an investment which will continue to increase in value annually. We also have various other funds, such as the Salomons Scholarship Fund, the David Hughes Scholarship Fund, the Wilde Benevolent Fund, and the Entrance Fee Fund, the money in connection with the latter having to be capitalised, and we have a General Fund, which is also well invested. The grand total is a matter of £36,203. I have much pleasure in seconding the motion for the adoption of the Accounts and Balance Sheet.

Mr. J. S. Raworth : May I ask the Treasurer one question about the General Fund? When a Member dies who has paid a life composition, do you take the sum that he has paid into the Life Compositions Fund out of it and put it into the General Fund, or do you allow it to go on after his death?

Mr. Hammond : The Life Compositions Fund, into which all amounts received in composition of subscriptions for life are paid is invested separately, and the dividends derived from the investments are paid into the General Fund.

The resolution was then put and carried unanimously.

Mr. W. M. Mordey : Mr. President and Gentlemen, The motion I have to propose is one of thanks to the two Institutions which extend to us their hospitality and allow us the use of their rooms. Those two Institutions, as you all know, are, firstly, the Institution of Civil Engineers, and, secondly, the Society of Arts, in whose rooms we are now met. I think that, although these votes of thanks are passed every year, we all feel that in no sense can they become mere formalities so far as our thanks are concerned to these two Institutions, and particularly to the Institution of Civil Engineers, which in more than one way has been our parent Society. We have heard to-night that, sooner or later, we shall not have occasion to pass this vote of thanks—that we shall some day have a building of our own. We began by having a Building Fund. We have now gone on a step further, and have got a site, and some day we shall have a building. But I do not think we shall even then cease to feel thankful to the Institution of Civil Engineers, because the satisfactory position we occupy as regards our Building Fund is largely the result of the privileges we have been able to enjoy in being able to hold our meetings at the Institution of Civil Engineers, and in having their support and co-operation in various ways. I have much

pleasure in moving, "That the best thanks of the Institution be tendered to the Council of the Institution of Civil Engineers, and to the Council of the Society of Arts, for the great privilege accorded to this Institution of holding their evening meetings in their rooms."

Mr. J. E. Kingsbury (Vice-President) seconded the proposal and the resolution was carried unanimously.

Mr. W. H. Patchell: Mr. President and Gentlemen, The motion which is put into my hands is, "That the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year." I think, as we are growing more and more, the importance of the posts held by these Local Secretaries grows with the Institution. We use them probably more than the ordinary Member thinks. In the matter of elections they are constantly referred to, though perhaps not quite so much at home as abroad. If a transfer paper or an election paper comes in and is not signed by the Local Secretary it is looked on that that man is not doing his honorary duty, and he is promptly written to! Then we also have to depend on these gentlemen for practically canvassing the districts in which they are resident, and that is a very important work. It has been suggested unofficially that the Local Sections should be kept in closer touch as regards brains and papers with London, and the closer we can keep in touch with the Local Sections the better it is for the Institution as a whole. It is therefore with very great pleasure that I move, "That the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year."

Mr. W. W. Cook: I have very great pleasure in seconding the resolution.

The resolution was put and carried unanimously.

Mr. H. Hirst: Mr. President and Gentlemen, As a member of the Finance Committee I have a particularly good opportunity of watching the doings of our Treasurer, to whom it is my privilege to propose a vote of thanks. I wish to assure the Members here that Mr. Hammond as a treasurer is unrivalled. He has brought into our system of book-keeping his unlimited business experience and excellent business method, and I am not afraid of stating that the business side of our Institution can be looked into by any auditor, and will compare favourably with any other scientific institution, or with any municipal council's undertaking, or well-organised business house. Our thanks are due to Mr. Hammond for his attention to details, and for the ungrudging way in which he gives us his time. It gives me great pleasure to move: "That the thanks of the Institution be accorded to Mr. R. Hammond for his kind services rendered during the past twelve months in his office of Honorary Treasurer."

Mr. S. Z. Ferranti: I have very much pleasure in seconding that resolution. I can assure you no one could more efficiently carry out the duties of Treasurer than Mr. Hammond.

The President: I have no doubt you will all most heartily concur in the warm terms in which Mr. Hammond's services have been recognised. He is, as you all know, energetic in private and public life, and

he is also energetic in looking after the pecuniary affairs of our Institution.

The resolution was then put and carried with acclamation.

Mr. R. HAMMOND: Mr. President and Gentlemen, I take the opportunity of thanking you for your very kind expressions of appreciation of my services and for re-electing me. It has given me very great pleasure for some years now to act in this capacity, and I promise you that during the coming year I will devote as much time as it is possible to spare to the duties of the Institution.

The PRESIDENT: Gentlemen, It has fallen to my lot to propose a vote of thanks in which pleasure and sorrow are mixed. The proposal I have to move is: "That the thanks of the Institution be given to the Honorary Auditors for their services during the past year." Unfortunately, since the election of the Council and the other officers of the Institution which took place recently, one of the Honorary Auditors, Mr. F. C. Danvers, who has acted in that capacity since the very foundation of this Institution as the old "Society of Telegraph Engineers," has passed away. Under the circumstances, whilst proposing a very hearty vote of thanks to our friend who is here present, I venture to couple with it a vote of condolence to the relatives of our late Honorary Auditor, Mr. F. C. Danvers. I need not say that the Honorary Auditor who is present is our friend Mr. Sidney Sharp, who has worked for us so heartily for very many years past.

Mr. R. J. WALLIS-JONES: Mr. President and Gentlemen, I feel quite sure that all the Members will agree with the very sympathetic expression which has fallen from the lips of our President with regard to the late Mr. Danvers. We all fully realise that the labour of our Honorary Auditors is increasing year by year, and we are greatly indebted to them for the work which they perform on our behalf. I have much pleasure in seconding the proposal "That the thanks of the Institution be given to the Honorary Auditors for their services during the past year."

The resolution was carried unanimously.

Mr. SIDNEY SHARP: Mr. President and Gentlemen, This evening I would prefer to have been spared acknowledging the vote of thanks to the Honorary Auditors, because of the recent death of the late Mr. Danvers, whom I looked upon not only as a co-Honorary Auditor, but as a personal friend. We had been associated together in this work for the last four or five years, and I had taken a great liking to him. He was a man of much information and a most pleasant companion. The only reason I rise is to express my own sorrow at his passing away, and to also say what enthusiasm he always threw into his work. I desire to associate myself with the remarks the President made of condolence with the family of our late Honorary Auditor, Mr. Danvers.

Mr. J. S. RAWORTH: I have a very congenial task to perform, namely, to propose "That the thanks of the Institution be tendered to Messrs. Wilson, Bristowe, & Carpmael for their kind services as Honorary Solicitors during the past year." I think there are probably very few of our Members who know how much these gentlemen have done

for us in the past. Having once occupied the position of a member of the Council, I do know something of what they have done for us. Their work is, to some extent, intermittent; but I hope that this excellent Council just elected will set to work and give our Solicitors a little more to do. I hope they will signalise this year of office by improving Article No. 38. I, as a Member of this Institution, can never feel quite happy so long as the clause remains, in which bankrupts and felons are classed together, and whereby the Council takes power to eject a Member without giving him a hearing if he be so unfortunate as to become a bankrupt. I have much pleasure in proposing "That the thanks of the Institution be tendered to Messrs. Wilson, Bristowe, & Carpmael for their kind services as Honorary Solicitors during the past year."

Mr. Leon Gaster having seconded the resolution, it was put and carried unanimously.

The President: I think, Gentlemen, although it is not on the agenda, that before I proceed to the other business of the meeting I should like to say a word as to the work of the Secretary and the secretarial staff. That work, even in quiet times, is always onerous. In the session that has not yet drawn to a close, as it will not terminate until November next, the work has been abnormally heavy. All those gentlemen who have had anything to do with the organisation of a meeting such as the great social gathering to which I made reference recently, will be able to form an adequate conception of the amount of organising work and general work that has fallen on the shoulders of our Secretary and his very able assistants. I feel sure that not only the Members of Council present, but the ordinary Members, will accord a very hearty vote of thanks to the Secretary and the secretarial staff for their energetic work, both in the past and during the present period of pressure.

The resolution was carried by acclamation.

The Secretary (Mr. Lloyd) having expressed his thanks on behalf of the staff and himself,

The President announced the result of the election of the new Council and the Honorary Officers for the year 1906–1907. Under the Articles of Association, no candidates other than those nominated by the Council having been put forward, the latter were declared to be duly elected. The Council and officers, therefore, consist of the following gentlemen:

President.

To assume office in November, 1906.

Dr. R. T. Glazebrook, F.R.S.

The Past Presidents.

The Chairmen of Local Sections.

Vice-Presidents.

F. Gill.	W. H. Patchell.
W. M. Mordey.	C. P. Sparks.

Members of Council.

W. A. CHAMEN.
W. DUDDELL.
S. EVERSHED.
H. E. HARRISON, B.Sc.
J. S. HIGHFIELD.
H. HIRST.
Col. H. C. L. HOLDEN, R.A., F.R.S.
WALTER JUDD.
GISBERT KAPP.
J. E. KINGSBURY.
C. H. MERZ.
M. O'GORMAN.
G. W. PARTRIDGE.
A. A. C. SWINTON.
C. H. WORDINGHAM.

Associate Members of Council.

ALBERT CAMPBELL, B.A.
T. MATHER, F.R.S.
J. HUNTER GRAY.

Honorary Auditors.

(*Vacant.*)
SIDNEY SHARP.

Honorary Treasurer.

ROBERT HAMMOND.

The meeting adjourned at 8.55 p.m.

EDUCATION AND TRAINING OF ENGINEERS.

Report of a Committee appointed by the Council of The Institution of Civil Engineers, adopted April 24, 1906.*

Members of the Committee:

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., *Chairman.*

ARCHIBALD BARR, D.Sc.
Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S.
Sir ALEXANDER R. BINNIE.
ALEXANDER GRACIE.
ROBERT KAYE GRAY.
HARRY E. JONES.
Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S.
HENRY LOUIS, M.A.
A. T. TANNETT-WALKER.
R. L. WEIGHTON, M.A.
J. HARTLEY WICKSTEED.

WE have the honour to submit the following Report and Recommendations for the consideration of the Council of The Institution of Civil Engineers, in accordance with the terms of Reference to this Committee, which was appointed—

> "To consider and report . . . as to the best methods of training for all classes of Engineers, including both scholastic and subsequent technical education; it being an instruction to this Committee that the principle shall be maintained that the education of an Engineer must include both practical experience and scientific training."

It is desirable to place on record, at the outset, a brief account of the circumstances under which the Committee was appointed, by unanimous Resolution of the Council, on November 24, 1903.

In taking this action the Council of The Institution of Civil Engineers proceeded on lines which had been followed for a long period, with a view to improvement in the training and status of Civil Engineers.

An exhaustive inquiry had been made in 1868 into then existing conditions and systems of engineering education in the United Kingdom and in foreign countries; and the results of this inquiry

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were published by the Institution in 1870. In 1891 another statement was published dealing fully with the facilities for Engineering education afforded at that date by the Engineering schools of Universities and Colleges in the British Dominions.

The educational qualifications required of candidates for admission as Students in 1889, and subsequently the system of examinations established in 1897 for Students and Associate Members of The Institution of Civil Engineers, furnished further proof of the importance attached by the Council to the higher education of Civil Engineers.

During the year 1903 renewed discussions of this subject took place at the Engineering Conference of The Institution of Civil Engineers, and at meetings of The Institution of Mechanical Engineers, The Institution of Naval Architects, and important Engineering Societies outside London. These discussions showed wide differences of opinion as to the best methods of training engineers, but indicated a general feeling in favour of thorough investigation of the subject by some body representing all branches of engineering, whose conclusions would command the attention of all who were interested in the education and training of engineers. This general desire was definitely expressed in a letter (of May 8, 1903) addressed by the President of The Institution of Mechanical Engineers to the President of The Institution of Civil Engineers, stating that the Council of the former Society considered it desirable that a representative Committee should be appointed by the Council of The Institution of Civil Engineers to consider and report on the whole subject of engineering education. This suggestion was the immediate cause of action by the Council of The Institution of Civil Engineers (November, 1903) after the summer vacation, when steps were taken to appoint the Committee whose work is now completed.

The Council then decided to request the Engineering Societies named below to assist the proposed inquiry by nominating representatives to serve thereon :—

The Institution of Mechanical Engineers.
The Institution of Naval Architects.
The Iron and Steel Institute.
The Institution of Electrical Engineers.
The Institution of Gas Engineers.
The Institution of Engineers and Shipbuilders in Scotland.
The Institution of Mining Engineers.
The North-East Coast Institution of Engineers and Shipbuilders.

All these Institutions complied with the request, and nominated representatives, and the constitution of the Committee was completed in February, 1904, as under :—

Sir William H. White, K.C.B., Sc.D., LL.D., F.R.S.,
Past-President Inst. C.E., *Chairman*.

The PRESIDENT of The Institution of Civil Engineers (*ex-officio*).

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., Past-President Inst. C.E.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., Vice-President Inst. C.E.

J. HARTLEY WICKSTEED, M. Inst. C.E. (*representing the Institution of Mechanical Engineers*).

ALEXANDER GRACIE, M. Inst. C.E. (*representing the Institution of Naval Architects*).

Sir EDWARD CARBUTT, Bart.,* M. Inst. C.E. (*representing the Iron and Steel Institute*).

R. KAYE GRAY, M. Inst. C.E. (*representing the Institution of Electrical Engineers*).

HARRY E. JONES, M. Inst. C.E. (*representing the Institution of Gas Engineers*).

Professor ARCHIBALD BARR, D.Sc., M. Inst. C.E. (*representing the Institution of Engineers and Shipbuilders in Scotland*).

Professor HENRY LOUIS, M.A. (*representing the Institution of Mining Engineers*).

Professor R. L. WEIGHTON, M.A. (*representing the North-East Coast Institution of Engineers and Shipbuilders*).

J. H. T. TUDSBERY, D.Sc., M. Inst. C.E., *Secretary*.

J. G. HENDERSON, B.Sc., Assoc. M. Inst. C.E., *Assistant-Secretary*.

As the members of the Committee were busily occupied and widely scattered over the country, it was felt from the first that much of the work must be done by correspondence, and that it would be advantageous before meetings took place to settle the heads under which the inquiry might be arranged most conveniently. For that purpose the following memorandum was prepared and circulated by the Chairman to the members of the Committee.

PROPOSED SECTIONS OF INQUIRY.

1. *Preparatory Education in Secondary Schools;* with special reference to suitable training of youths who are intended for the Engineering profession in Mathematics, Elementary Science, Modern Languages and Handicrafts.
2. *Training in Offices, Workshops, Factories, or on Works;* including the decision as to the period or periods at which such training can best be given, its character and duration. The possibility to be considered of giving to the preliminary stages of this practical training as broad a character as possible, so as to prepare students for any branch of engineering they may subsequently enter.
3. *Training in Universities and Higher Technical Institutions.*

   Opinions to be formed as to :—

   (*a*) The most suitable age at which average students could begin this course.

   (*b*) The possibility of arranging the earlier courses of study so as to be common to all branches of engineering.

* On the regretted death of Sir Edward Carbutt, in October, 1905, Mr. A. T. Tannett-Walker, M. Inst. C.E., was appointed to serve on the Committee as a representative of the Iron and Steel Institute.

(*c*) The duration of such common courses of study.

(*d*) The extent to which specialisation should be provided for in technical institutions, and the extent to which it should be carried.

4. *Post-Graduate Work.* How it can best be organised and maintained :—

(*a*) At Universities and higher technical institutions.

(*b*) On actual works, and in mines, factories, etc.

At the first meeting of the Committee (held on February 24, 1904) this memorandum was approved, and it was decided to entrust detailed consideration of the first section (Preparatory Education in Secondary Schools) to a sub-Committee, consisting of Sir Alexander Kennedy (chairman), Professors Archibald Barr, Henry Louis, and R. L. Weighton, and Mr. Alexander Gracie. It was further agreed that the Committee as a whole should undertake the consideration of (*a*) Practical training in offices, workshops, factories, or on works, and (*b*) Training in Universities and higher technical institutions.

In prosecuting their inquiries the Committee thought it essential to obtain, either orally or in writing, the opinions of persons having experience in engineering education, and of eminent engineers practising in various branches of the profession. It was desired to make this record of opinion precise, representative, and comprehensive; for which purpose members of the Committee undertook to suggest the form in which inquiries should be framed, to give the names of those to whom application might be made, and to indicate general detailed action, which, in their judgment, would be of value in the collection of opinions and information. These suggestions were summarised and condensed, under the supervision of the Chairman, by the secretary and assistant secretary. The schedules of questions approved by the Committee and subsequently issued were prepared on this basis.

These preliminaries necessarily occupied a considerable time and entailed a large amount of correspondence. Their final result has been the attainment of both definiteness and wide range in the questions circulated, and has secured the collection of a great body of opinion from representative engineers in active practice, professors and teachers in technical colleges and Universities, and others whose advice has been of value in reaching a decision on matters referred to the Committee. The scope of their inquiry was necessarily extensive, and the Committee desire to express their gratitude to the large number of gentlemen who have favoured them with advice and opinions. They recognise that those who have given assistance are actively engaged in educational and professional work, which made it no easy matter to devote attention to the questions asked. On the other hand, the numerous and full responses made by men whose experience gives authority to their opinions and recommendations, have enabled the Committee to proceed with greater certainty in framing their Report. Diversities of opinion have been disclosed in regard to some details, as was inevitable from the nature of the subjects; but in all main features

of their recommendations the Committee have support from the large majority of their professional colleagues and of the teachers in Universities and higher technical institutions. This fact cannot fail to carry great weight with those for whose benefit the Report has been prepared.

The Committee are of opinion that it would not have been possible in any other way to have secured equally full consideration of the subject, or so valuable a mass of information and opinion in regard to the principles it is desirable to follow in training engineers. More time and labour have been involved by adopting the method of written communication instead of oral evidence ; but a much larger number of men has been reached, and the final result is more satisfactory.

I. Inquiry as to Preparatory Education. (*See Appendix I.*)

The details of this portion of their work were entrusted by the Committee to the above-mentioned sub-Committee. A schedule of the questions issued by the sub-Committee will be found in Appendix I., which also contains an analysed summary of the replies. This Schedule was issued to 120 representatives of the following classes :—

(1) Teachers in engineering colleges.
(2) Headmasters of secondary schools at which it is believed special attention is paid to scientific training.
(3) Engineers not engaged in teaching.

Replies were received from 80 per cent. of the gentlemen whose opinions were invited, and from these replies definite conclusions were deduced as to the prevalent opinions on points raised by the questions.

The report which the sub-Committee submitted to the main Committee was considered at a meeting held on March 23, 1905, and was then approved and adopted.

The following are accordingly the recommendations of the Committee in respect of the most suitable preparatory education for boys who are intended to become engineers.

RECOMMENDATIONS IN RESPECT OF PREPARATORY EDUCATION.

1. It is desirable that a boy intended for the Engineering profession should, before leaving school and commencing to specialise, have attained a standard of education equivalent to that required by the Institution Studentship Examinations, and that he should not commence his special training until he is about 17 years of age.

2. A leaving examination for secondary schools, similar in character to those already existing in Scotland and in Wales, is desirable throughout the United Kingdom. It is desirable to have a standard such that it could be accepted by the Institution as equivalent to the Studentship Examination, and by the Universities and Colleges as equivalent to a Matriculation Examination.

3. Advanced teaching of History and Geography, with instruction and practice in Essay-writing and in Précis-writing, should be included

in the ordinary school curriculum, and the instruction in English subjects should include at least an introduction to English Literature.

4. Greek should not be required, but an elementary knowledge of Latin is desirable. The study of Latin should, however, be discontinued during the last two years of attendance at school, or after the standard required for the leaving certificate has been attained. Modern languages, especially French and German, should be studied, and should be taught colloquially or in such a way as to give the pupils a practical knowledge of each language, sufficient to enable them to study its literature and to converse in it with some degree of facility.

5. Instruction in Mathematics should be given by methods differing considerably from those usually adopted in the teaching of this subject merely as an intellectual exercise. The geometrical side of Mathematics should be fostered, and before they leave school boys should be conversant with the use of logarithms, and with at least the elements of trigonometry, including the solution of triangles. It is also of importance that instruction in practical arithmetic should be carried further than has been generally the case hitherto, with the object especially of encouraging the use of contracted methods and operations in mental arithmetic, and of encouraging also the expression of results with only such a degree of (numerical) precision as is consistent with the known degree of certainty of the data on which they are or may be supposed to be based.

6. It is preferable that boys should attain at school a general knowledge of elementary Physics and Chemistry, or what is sometimes called "Natural Philosophy," rather than that they should pursue in detail some particular department of science.

7. Special attention should be given to drawing; the instruction should include ordinary Geometrical Drawing with orthographic projection, Curve-drawing, Freehand Drawing, and Practical Mensuration.

8. Work in the nature of handicraft, such as Carpentry or Turning, or elementary field-surveying, may be encouraged as a recreation but should not be required as a school exercise.

9. It appears to be impossible, in the general curriculum of school work, to include advantageously time for instruction in such a subject as Surveying, which has been suggested.

The Committee recommend that this scheme of Preparatory Education should be officially communicated to the Board of Education and widely circulated amongst those engaged in the conduct of Secondary Schools and Engineering Colleges, in order that future schemes of tuition of youths who contemplate entry into the Engineering profession may be guided thereby. The Committee are of opinion that if this course is taken it would assist in overcoming one great difficulty now universally felt in institutions in which applied science is taught. At present a considerable proportion of students enter technical institutions ill-prepared, and at least one year has to be devoted to instruction which ought to be secured beforehand. Proper preparation is essential if students are to derive full benefit from special instruction in applied science. Professors and teachers ought not to be required

to undertake subjects that should be taught elsewhere, but should be left free to devote themselves to scientific and technical instruction, which is their real work.

II. Inquiry as to Engineering Training. (*See Appendix II.*)

The Committee found it convenient to deal with Sections 2, 3 and 4 of the inquiry together. These include Training in Offices, Workshops, Factories or on Works, generally designated "practical" training: Training in Universities and Higher Technical Institutions: and Post-Graduate Work. In these instances also, as explained above, a schedule of questions was framed (Appendix II.) and was circulated widely; but the Committee embodied in the Schedule their conclusions on certain important subjects which had been thoroughly discussed by the members, and on which they were unanimous. In that course there was no interference with the free expression, by those whose opinions were solicited, of views contrary to those of the Committee; and the replies indicated clearly that this fact was realised. Nor were the comments of correspondents limited to points raised in the Schedule. On the contrary, perfectly independent statements of opinion were submitted in many cases. The Committee desired primarily to ascertain the views of men whose opinions were entitled to respectful consideration, in consequence of their experience and study of education and of Engineering training. In all instances these communications have received due consideration by the Committee after being carefully grouped and analysed.

Each member of the Committee was at liberty to forward the names of gentlemen to whom schedules should be sent, and each Institution was asked officially to suggest names, in order that the list might be made as complete as possible, and that each department of Engineering might be adequately represented. The total number of schedules issued was 676, and the total number of replies received was 267. Their distribution over different branches of the profession may be classified roughly as follows:—

	No. of Schedules issued.	No. of Replies received.
1. Engineers engaged in constructional work (railways, docks, harbours, canals, waterworks, sewerage, etc.)	34	16
2. Mechanical Engineers	200	82
3. Mining Engineers...	72	22
4. Iron and Steel Manufacturers	47	16
5. Naval Architects, Shipbuilders and Marine Engineers	110	32
6. Gas Engineers	94	39
7. Electrical Engineers	66	30
8. Professors, and others who are, or have been, engaged in teaching	44	30
	676	267

The gentlemen whose opinions were asked were actively engaged in professional work, and in consequence there were delays in making replies. Repeated applications were necessary before the inquiry could be completed, and it was decided finally to make November 1, 1905, the latest date for the receipt of replies.

An analysis of the replies is given in Appendix II. From this it will be seen that the tentative suggestions and recommendations embodied by the Committee in their Schedule have received very general support ; this support has been given by each of the great sections of the Engineering profession. A few correspondents expressed radically different views ; but, in the main, the opinions of the Committee have been endorsed, and this result is satisfactory, since it indicates the possibility of practical effect being given to the recommendations. The Committee were not assisted so fully by replies to their question on mathematical teaching as to others ; they therefore obtained specially the opinions of their colleagues engaged in tuition, and of other gentlemen who have large experience in this matter.

The Committee have had in view throughout what may be termed an "average boy," of ordinary ability, whose parents are in a position to secure for him a thorough training before he begins his actual professional work as an engineer. They recognise the necessity that will always exist for providing also suitable means of training for young men not so favourably situated, who work their way by sheer ability and force of character, and whose earlier careers do not permit of the methodic preparatory education and training which they consider best for the average boy. The Committee also recognise the certainty that other most valuable recruits for the Engineering profession will continue to enter at a later period of life, and from other systems of education and employment. At the same time, it is obvious that, in all such cases, men may be trusted to find their way, and to avail themselves of existing opportunities for instruction and training. Their concern, therefore, has been with the best general scheme adapted to the average boy.

The Committee have not overlooked the established customs of Universities and Colleges to which Engineering Schools are attached, and have given weight to the necessity for arranging terms and courses of study with due regard to general efficiency in the conduct of these Institutions. Consequently they do not recommend absolute uniformity of arrangement in college courses of study or in their method of association with practical training ; nor do they consider such uniformity necessary. In Scotland, it may be anticipated that the alternation of winter study at the Universities with long summer vacations, usually spent in practical work, will be continued ; whereas in England the sessions and vacations will be arranged differently. Other varieties of practice exist or will be introduced : and, in the judgment of the Committee, considerable latitude is permissible in these matters without loss of educational efficiency.

RECOMMENDATIONS IN RESPECT OF ENGINEERING TRAINING.

The Committee desire to preface these recommendations by the statement that they are unanimous in the opinion that engineering training must include several years of practical work, as well as a proper academic training. Long experience has led to general agreement amongst engineers as to the general lines on which practical training should proceed; and it has, therefore, been unnecessary to deal at any great length with that matter in the recommendations. It must not be supposed, however, that the fuller treatment of academic training in the following pages indicates its greater relative importance; the reason for this fuller treatment is to be found rather in a desire to suggest courses of study which can be best associated with the practical training that is essential to engineering education.

Taking the Schedule of opinions and questions relating to practical training (Appendix II.) as determining the order followed, the Committee make the following Recommendations. The numbers refer to the sections of Appendix II.

1. The average boy should leave school when he is about 17 years of age. Much depends upon the development of individual boys, but the minimum age should be 16 and the maximum 18 years.

2. The practical training should be divided into two parts, whenever that arrangement can be made; and the preliminary stage of practical training should consist in all cases of at least a year spent in mechanical engineering workshops. This "introductory workshop course" is desirable even when students do not contemplate devoting themselves at a later stage to what is generally designated "mechanical engineering." Thus, for mining engineers, the machine shops of a large colliery would be found especially suitable. The Committee are supported in this recommendation by the opinions expressed by a large proportion of the engineers who have been consulted. It is recognised that at present there are practical difficulties in arranging for this workshop year being interposed between the school and college work, and that employers may consider the arrangement objectionable in their interests. On the other hand, the Committee suggest that these difficulties should not be insurmountable; and the general agreement as to its advantageous effect on training leads them to hope that practical trial may be given to the suggestion. In any case, the Committee recommend that an "introductory workshop course" of at least a year should be included whenever possible in the practical training of all engineering students. Where the "introductory workshop course" is possible before the college training, it should not be less than one year, nor more than two years. The longer period may be desirable in the case of boys who are to become mechanical engineers, and useful in all cases when boys leave school at 16 years. In some cases it may be preferred to take the workshop course after the first year of the college training common to all branches of

Engineering. An interruption of college training at a later period must involve great disadvantages.

3. During workshop training boys should keep the regular working hours, should be treated like ordinary apprentices, be subject to discipline, and be paid wages.

4. Nothing should be done in the form of evening study which would impose undue strain upon the physique of boys. In some cases this might prevent attendance at evening classes ; but experience shows that many boys can attend such classes without physical injury and with great educational advantage. The Committee think it is most important that all boys should at least maintain their scholastic acquirements during the introductory workshop course, and, for the class of boys in question, it is considered that this result might be secured, by private tuition or otherwise, without undue physical strain. Nothing should be done to discourage boys, who so desire and are physically fit, from adding to their knowledge either by private study or by attendance at classes.

5. As a rule, it is preferable to proceed to a technical college or University on the completion of the introductory workshop course. This is advantageous to most boys, as it abridges the period between school and college, and lessens the danger of retrogression in knowledge. It also facilitates the arrangement of common courses of study for junior students in technical colleges and Universities ; and, on the whole, gives the students better opportunities of benefiting by college training.

In some cases—as, for example, when boys are intended to become mechanical engineers—it may be advantageous to complete the practical training before entering college ; but, if this is done, it becomes more important that simultaneous education during practical training should be secured by private tuition or in evening classes ; otherwise boys would lose seriously during four or five years' suspension of systematic study, and would be disadvantaged on entering college.

The alternation of college study and practical training is only feasible when (as in the Scotch Universities) the college vacation practically occupies half the year ; or in the case of mining engineers, where the official requirements under the Coal Mines Regulation Acts prescribe a minimum period of four months spent in mines before the termination of the college course.

6. For the average student the period of college study should be three sessions, provided he is well prepared before entering college. In the case of students who desire to follow up the science of their profession, a fourth year might be added, which would be in some cases post-graduate work, and might come after the practical training is completed. In cases where students are exceptionally well-prepared before entering college, or are above the ordinary age, or possibly without the means required for a full course of study, facilities should be given for shortening the course of study.

In all cases the first session might be advantageously devoted to a common course of study by average students, and probably that

common course might be extended into the second session without loss to final specialisation.

7. A sound and extensive knowledge of Mathematics is necessary in all branches of Engineering, although some of these branches require more advanced mathematics in their practice than others. The capacity for acquiring mathematical knowledge varies greatly in individual students, and many who become competent engineers have not the power of acquiring the higher mathematics. These differences of actual requirements and individual capacity must be recognised in courses of instruction, and can hardly be dealt with by any general statement.

It should be possible, however, for the student of average ability who, at his entry upon the study of applied science, has advanced to the stage of preparation in mathematics outlined in the foregoing recommendation as to preparatory training (see page 419) to master sufficiently during the common course of instruction for all engineering students the subjects included under the category of pure mathematics; provided the instruction proceeds in a systematic and well-considered manner.

The Committee endorse the practically universal recommendation, made by those whose special knowledge and experience entitle them to speak with authority, that a sufficient time should be allotted to the study of pure mathematics during the common college course, to permit the best students to obtain a sound knowledge of Algebra, Trigonometry, Analytical and Practical Plane Geometry, the elements of Solid Geometry, and a working knowledge of the Differential and Integral Calculus, and of the simpler Differential Equations. To this fundamental mathematical training there must be added instruction in Applied Mathematics and Mechanics. The extent to which individual students can be carried in this course must be a matter left to the discretion of the teaching staff, whose means of observation and power of assessing the capability of individual students can alone decide the matter. In the judgment of the Committee, it is most important that, when teachers consider that individual students are lacking in the power of proceeding successfully with their higher mathematical studies, time should not be wasted in persevering therewith. On the other hand, many students of this class under proper instruction are capable of benefiting greatly by well-considered courses of instruction in the practical applications of mathematics.

In the later terms of the college course of study, time devoted to purely mathematical instruction should be lessened as compared with the time similarly devoted during the earlier terms, and that given to specialised instruction in engineering subjects should be increased. The most advantageous arrangement, both for students and teachers, will consist in the combination of mathematical and engineering instruction by the professors and teachers of engineering. The teachers of pure mathematics also, in dealing with the students during their common course of study, should be well informed as to the

applications of mathematics in engineering, so that their courses of instruction may be arranged suitably, and that departments of these subjects having no bearing upon engineering may not have given to them unnecessary time or attention.

With regard to the teaching of geometrical drawing, physics, chemistry, and geology, the existing arrangements of the Universities and technical colleges appear to be satisfactory and to meet all cases.

Without interference with the organisation of individual colleges, it would be found in the highest degree beneficial to arrange conferences between the staffs of all the important teaching institutions, so that a uniformly high standard of qualification on the part of students at the completion of their courses of study may be maintained.

8. At least three to four years should be spent in practical training, inclusive of the "introductory workshop course" previously mentioned. The Committee favour a total period of four years' practical training where it can be secured, this being carried out in workshops, on works, in mines and in offices, as may be required in each case. It is highly desirable that a part of this practical training should be obtained in drawing-offices.

9. Where college training is completed before practical training is taken, the total period devoted to the latter should be three years in ordinary cases. Exceptional ability may justify a somewhat shorter period. The hours of work should be the same as if the usual course were followed; the wages paid should be somewhat higher, especially in the later years. The Committee make this general recommendation whilst recognising that this is not the practice in mining.

10. The Committee recommend strongly efficient instruction in engineering drawing.

Instruction in testing materials and structures, and in the principles underlying metallurgical processes and other practical operations incidental to the branch of engineering in which a student proposes to specialise, should be included in the college course.

In regard to workshop practice in technical colleges, they are of opinion that boys who have spent one or two years in mechanical engineering workshops should not be instructed in workshop practice at technical colleges.

11. In connection with the grant of degrees, diplomas, and certificates to engineering students, considerable importance should be attached to laboratory and experimental work performed by individual students, as well as to their progress in mathematical and scientific studies, and degrees, etc., should not be granted on the results of terminal or final examinations alone. Practical unanimity is shown in regard to this procedure by those whose opinions were obtained, and it is considered to be of great importance in assessing the professional attainment of students.

12. Facilities for, and organisation of, post-graduate work by engineering students in Universities and higher technical institutions should be considerably increased. This recommendation is made with the special object of encouraging qualified students to undertake

researches which may prove of practical value to engineering operations and processes. The number of such students is not likely to be large at any time, but their influence on younger students should be highly beneficial, and the advantage to engineering and industry should be considerable. In many cases the best period for post-graduate work would be that following the completion of practical training, even when that training follows the college course.

13. The Committee reaffirm the conviction expressed when they issued their inquiry, that the sympathetic assistance of employers is essential to improvement in engineering education and training.

In conclusion, the Committee desire to express their indebtedness to the Secretary (Dr. Tudsbery) and the Assistant-Secretary (Mr. Henderson) for the valuable and unwearied assistance which they have rendered throughout the inquiry, and would repeat their acknowledgment of indebtedness to all those who have assisted with opinions and information.

W. H. WHITE,
Chairman of the Committee.
J. H. T. TUDSBERY,
Secretary.

April 7, 1906.

APPENDIXES.

APPENDIX I.

SCHEDULE OF QUESTIONS RELATING TO PREPARATORY EDUCATION AND TRAINING OF ENGINEERS, ISSUED BY THE SUB-COMMITTEE, WITH A SUMMARY OF THE REPLIES RECEIVED.

QUESTION.	SUMMARY OF REPLIES.	
		Per Cent.
1. What is the proper age for leaving school, having in view the fact that the boy has ahead of him a practical and theoretical training which will cover certainly 4, probably 5, and perhaps 6 years before he can become a regular assistant in any branch of engineering work?	Average age recommended—	
	Less than sixteen	4·5
	Sixteen	19·0
	Between sixteen and seventeen	14·0
	Seventeen	40·0
	Between seventeen and eighteen	4·5
	Eighteen	10·0
	Exceeding eighteen ...	8·0
		100·0
		Per Cent.
2. (*a*) What is your view as to the desirability of a leaving examination for Secondary Schools?	(*a*) Desirable	90·0
	Undesirable	10·0
		100·0
(*b*) If such an examination is possible or desirable, should it be in the hands of the school itself, or of external examiners, or of both conjointly?	(*b*) School itself	5·0
	External examiners ...	41·0
	Both conjointly	54·0
		100·0
(*c*) Could it, and, if so, should it, be utilised as the equivalent of a matriculation or entrance examination for the various colleges giving education to engineers?	(*c*) Yes	93·5
	Doubtful	6·5
		100·0
		Per Cent.
3. English Subjects. (*a*) Is it possible to develop further than has generally been the case hitherto, the teaching of History and Geography in what may be called their commercial aspects?	(*a*) Yes	85·5
	Not desirable	14·5
		100·0
(*b*) Could Précis-writing be included under this heading?	(*b*) In favour	84·0
	Doubtful or not in favour ...	16·0
		100·0
(*c*) Can anything be done to give extended instruction and exercise in Essay-writing?	(*c*) In favour	88·0
	Doubtful or not in favour ...	12·0
		100·0

APPENDIX I.—*continued.*

QUESTION.	SUMMARY OF REPLIES.
4. Languages. (*a*) How far is it desirable that boys definitely intended for the Engineering profession should continue the study of the classical languages, or of either of them, until the time when they leave school?	Per Cent. (*a*) In favour ... ... 47 Recommend discontinuance at least 2 years earlier ... 41 Recommend omission of classics altogether 12 100
(*b*) If it is thought that the study of these subjects ought to be continued to the end, what amount of time should be spent upon them during the last two years?	(*b*) About 5 or 6 hours a week ... 77 About 10 hours a week ... 23 100 The replies to (*a*) and (*b*) refer, in the majority of cases, to Latin alone, the general opinion being that Greek may be either omitted entirely or discontinued at an earlier stage.
(*c*) To what extent can **Modern Languages**—especially French and German—be taught colloquially or in such fashion as to make them really useful, without the expenditure of unnecessary time on theoretical grammatical exercises or in the study of classical comedies?	Per Cent. (*c*) Approve of this method ... 77 Doubtful or not in favour ... 23 100 In many cases residence abroad is recommended as the only means of acquiring a real colloquial knowledge of modern languages.
5. Mathematics. (*a*) Can general mathematical teaching be given to boys who intend to become engineers in such a way as to help them later on in the practical use of mathematics—such a method of teaching naturally differing much from the method which would be used if mathematics were to be merely an intellectual exercise, not actually employed later on in real life, nor even used for the sake of passing an examination? (It has to be remembered that in the great majority of cases the boys whose natural bent is towards engineering find the geometrical side of mathematics fairly easy, but have difficulties with its analytical side. It is considered desirable also that boys leaving school for engineering training should have more than the mere minimum represented by four books of Euclid, etc. They ought certainly to know something about Logarithms and the elements of Trigonometry, and also about Similar Figures. It is thought that ample opportunity for such teaching could be found by the omission of the matters mentioned in (5) below.)	Per Cent. (*a*) In favour ... ... 85 Not in favour 15 100

APPENDIX I.—*continued.*

QUESTION.	SUMMARY OF REPLIES.
5. Mathematics—*continued.* (*b*) Is it desirable that the teaching of Mathematics at school should be arranged with a view to attain all or any of the following objects?— 1. The practical use of arithmetic with the special object of obtaining correct results independently of the mere study of arithmetical methods.	(*b*) Per Cent. 1. Yes ... ... 81 No 19 100
2. The encouragement of the use of contracted methods.	2. Yes ... ... 91 No 9 100
3. The encouragement of exercises in mental arithmetic.	3. Yes ... ... 94 No 6 100
4. The teaching, at this stage, of what Professor Perry has called "Practical Mathematics," of the use of Logarithms, of elementary Trigonometry (limited, for example, to right-angled triangles), of the general ideas of Projective Geometry, including points and lines at infinity, and the use of the slide-rule.	4. Yes ... ... 85 No . . .. 10 Omit slide-rule 5 100
5. The elimination from instruction in Mathematics of such matters as Cube Root Extraction and elaborate Algebraic Equations, which are purely intellectual gymnastics without any direct usefulness.	5. Yes ... ... 90 No 10 100
6. Science. (*a*) Is it better that boys should be made superficially familiar with the general language and ideas of Elementary Physics and Chemistry, or that they should be carried somewhat further in one particular section of such work?	Per Cent. (*a*) Recommend former ... ... 67 " latter ... ... 23 " both conjointly 10 100
(*b*) Would it be advisable rather to encourage the general study of what used to be known as "Natural Philosophy" as a subject of general mental training as well as of practical interest? (It has been a matter of common complaint among Engineering Professors that in many cases the mechanical ideas imbibed by schoolboys have done more harm than good in their subsequent study of the subject. If, however, it were possible	(*b*) Yes ... ... 78 No 22 100

APPENDIX I.—*continued.*

Question.	Summary of Replies.
6. Science—*continued.* to give schoolboys a thorough grounding in the elements of Mechanics, it would, of course, be useful.) (*c*) In view of the results hitherto obtained, would it be well to omit Theoretical Mechanics altogether from school teaching?	Per Cent. (*c*) Yes ... ... 77 No 23 100
7. Practical Work. (*a*) How far has it been found desirable that schoolboys should have, as a school exercise, practice in ordinary handicraft work, such as Carpentry or Turning?	Per Cent. (*a*) Undesirable as a school exercise ... ... 44 Desirable ... ... 38 Desirable in some cases, or to a limited extent ... ... 18 100 In many cases it is recommended that the boys should be encouraged to take up handicraft work, as a recreation, out of school hours.
(*b*) To what extent has it been found better and more useful to make the "practical" work really into Laboratory Exercises or Experiments, whether Physical, Chemical, or Mechanical?	Per Cent. (*b*) Consider it desirable and practicable ... ... 38 Consider it desirable... ... 42 Do not recommend this method 20 100
8. Drawing. What are your views as to the following schemes of instruction in Drawing to be taught in school to boys who are going afterwards into Engineering?	
(*a*) The ordinary teaching of Geometrical Drawing with orthographic projection, including especially curve drawing, both by co-ordinates and by purely projective methods.	Per Cent. (*a*) Desirable ... ... 92 Undesirable 8 100
(*b*) Free-hand Drawing from ordinary drawing-class models or from solids representing simple details of an engineering character.	(*b*) Desirable ... ... 96 Undesirable 4 100
(*c*) The drawing, in orthographic projection, of objects from actual measurement, a subject which has been called Practical Mensuration.	(*c*) Desirable ... ... 83 Undesirable 17 100
9. Surveying. Is it desirable, and, if so, is it possible to include anything like instruction in simple chain surveying, without optical instruments, for boys during their school period?	Per Cent. Undesirable ... ... 53 Possible and desirable ... ... 31 Desirable 16 100

APPENDIX II.

Schedule of Opinions and Questions relating to Training in Offices, Workshops, Factories, or on Works; and in Technical Colleges and Universities; with a Summary of the Replies Received.

Comments and replies are invited upon the following opinions and questions. In making them it is requested that answers be given with special reference to boys of average ability, who are destined for the Engineering profession and who have sufficient means to go through a full course of training.

Alternative suggestions will be welcomed and will receive full consideration.

Opinion or Question.	Summary of Replies.	Per Cent.
1. The Committee are of opinion that the age for leaving school should be about 17 years.	Agree	70
	Prefer sixteen	17
	Prefer eighteen	7
	Prefer fifteen	4
	Other replies	2
		100
2. (*a*) The Committee are of opinion that it is desirable that the course of training for all branches of Engineering should include at least one year's training in Mechanical Engineering workshops, where, ordinarily, information would be gained of the practical applications of electricity. (This is referred to hereafter as the "*introductory workshop course.*")	(*a*) Agree	72
	One year too short ...	21
	Do not agree	4
	Other replies	3
		100
(*b*) The Committee think that this introductory workshop course should be taken at an early period—either previously to the commencement of college training, or after that portion of the college training which is common to all branches of Engineering (*see* 6 below) has been completed.	(*b*) Agree	33
	Before college	47
	After common portion ...	10
	Complete college first ...	5
	Alternating with college ...	3
	Other replies	2
		100

APPENDIX II.—*continued.*

Opinion or Question.	Summary of Replies.
3. The Committee are of opinion that during this (and any subsequent) course of training in workshops, boys should keep the regular working hours, including early morning attendance, and should be treated like ordinary apprentices, and be paid wages.	Per Cent. Agree ... ... 79 Do not agree entirely ... 8 Shorter hours if attending evening classes ... ... 7 Should not be paid wages 5 Other replies 1 100
4. Is it desirable, having regard to the age and physical development of the boys— (*a*) To require them to attend classes for evening study during this introductory workshop course; or, (*b*) That this period should be devoted entirely to practical work —ordinary educational work being meanwhile suspended?	Per Cent. (*a*) and (*b*) Former preferable ... 55 Latter preferable ... ... 35 Former, with shorter working hours ... ... 3 Depends on individuals ... 2 Other replies 5 100
5. Assuming such an introductory workshop course to be approved for all boys, is it recommended— (*a*) That it should be followed by a period of study in a technical college or University before specialisation in particular branches of engineering is undertaken; or (*b*) Is it considered preferable that this workshop course should be at once followed by a period of practical training in the branch of engineering for which the boy is intended; or (*c*) Is it deemed desirable that the period of college study should be arranged so as to alternate with the workshop or other practical training—and, if so, in what manner?	Per Cent. (*a*) and (*b*) Former preferable ... 64 Latter preferable ... ... 31 Other replies ... ... 5 100 (*c*) Desirable ... ... 63 Undesirable ... ... 29 Difficult to arrange ... 5 Desirable in some cases ... 1 Other replies ... ... 2 100 Of those who consider the course indicated in (*c*) desirable, 42 per cent. recommend attendance at college during the winter 6 months, and at the workshop during the summer 6 months, in each year.

APPENDIX II.—*continued.*

Opinion or Question.	Summary of Replies.		
		(a)	(b)
		Per Cent.	Per Cent.
6. The Committee are of opinion that the earlier course of college study should be arranged so as to be common to all branches of engineering. This being assumed— (a) How long a period should be assigned to such common course of study? (b) What is a reasonable total period of college study for a boy of average ability?	One session	38	2
	One or two sessions ...	6	...
	Two sessions	42	15
	Two or three sessions ...	2	7
	Three sessions	5	51
	Three or four sessions ...	1	9
	Four sessions	2	11
	Four or five sessions ...	...	1
	Five sessions	...	1
	Other replies	4	3
		100	100

Opinion or Question.	Summary of Replies.	(a)	(b)	(c)	(d)	(e)
		Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
7. To what extent should college study be carried, in (a) Mathematics? (b) Geometrical Drawing? (c) Physics? (d) Chemistry? (e) Geology?	Recommend standards comparable with that of B.Sc. (in engineering) of London University	54	10	11	8	7
	The more the better	23	23	27	18	15
	Advanced instruction	13	32	28	23	12
	Elementary instruction	...	17	18	18	34
	Should be taught with regard to its application in engineering	...	9	...	2	5
	Include laboratory ...	...	...	6	20	...
	Should be optional ...	...	...	...	...	15
	Other replies ...	10	9	10	11	12
		100	100	100	100	100

Opinion or Question.	Summary of Replies.	
		Per Cent.
8. Apart from the introductory workshop course, what is considered to be a reasonable total period of practical training on works, in factories, workshops, mines, etc., when the age of specialisation is reached?	One year	4
	One to two years	3
	Two years	21
	Two to three years	11
	Three years	31
	Three to four years	5
	Four years	8
	Four to five years	1
	Five years	4
	Over five years	3
	Other replies	9
		100

APPENDIX II.—*continued.*

OPINION OR QUESTION.	COMMENT OR ANSWER.

9. In cases where boys complete their college training before beginning their practical training, what is thought best—considering that they must now be about 21 years of age—

(*a*) In regard to the introductory workshop course?

(*b*) In regard to the period required for specialisation in particular branches of engineering?

(*c*) In regard to hours of work and payment of wages in workshops, drawing-offices, mines, works, etc., during such period of specialisation?

	(*a*)	(*b*)	(*c*)
	Per Cent.	Per Cent.	Per Cent.
Same as if taken earlier	33	33	76
May be shortened ...	4	1	...
Should be omitted ...	26	...	...
One year	19	5	...
Eighteen months ...	2	3	...
Two years	5	17	...
Two to three years ...	...	5	...
Three years	3	19	...
Four years	...	4	...
Until proficient ...	...	2	...
Wages should be higher	...	...	10
Other replies ...	8	11	14
	100	100	100

Would your suggestions in the foregoing respects differ, and, if so, to what extent, in cases where practical training preceded or alternated with the college course?

With only a few exceptions, the replies to this question are all in the negative.

Entire disapproval of the course referred to in (**9**) is expressed in more than 50 per cent. of the replies.

10. Is it desirable to provide, and, if so, on what scale, in technical colleges, appliances and equipment for instructing students in—

(*a*) Engineering drawing?

(*b*) Workshop practice?

(*c*) Testing materials or structures?

(*d*) Metallurgical processes?

(*e*) Other practical operations incidental to engineering works?

	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Yes; in general, scale to be limited only by the funds at disposal ...	80	48	86	69	71
No	6	36	2	10	13
Doubtful	...	...	...	6	2
On small scale only	...	9	...	9	...
Moderate equipment	...	...	8	...	...
In some colleges ...	...	...	...	2	...
To teach principles	6	3	...	...	7
To illustrate lectures	2	2	1	1	2
Include principles of design	3	...	...	...	...
Other replies ...	3	2	3	3	...
	100	100	100	100	100

APPENDIX II —*continued.*

OPINION OR QUESTION.	COMMENT OR ANSWER.	Per Cent.
11. The Committee are of opinion that it is desirable, in connection with the grant of degrees, diplomas, and certificates to engineering students, that considerable importance should be attached to laboratory and experimental work performed by individual students, as well as to their progress in mathematical and scientific studies, rather than that degrees, etc., should be granted on the results of terminal or final examinations alone.	Agree	91
	Not too much importance ...	2
	Already being done	2
	Reports from works also desirable	2
	Other replies	3
		100
12. The Committee are of opinion that facilities for, and organisation of, post-graduate work by engineering students in higher technical institutions should be considerably increased.	Agree	83
	Do not agree	5
	Scholarships required ...	2
	By specially qualified students only	3
	Difficulty to attract the best men	1
	Other replies	6
		100
13. The Committee are of opinion that the improvement of engineering education depends greatly on the attitude of employers towards the suggestions foreshadowed in this memorandum; and the Committee would especially urge upon employers the importance of extending facilities to engineering students for the prosecution of post-graduate work.	Agree	74
	Do not agree	4
	Employers willing to grant facilities	7
	Students must show themselves capable	4
	Difficulties in the way ...	3
	Other replies	8
		100

OBITUARY NOTICES.

W. STRATFORD ANDREWS passed away on May 4, 1906, at his residence, at Sevenoaks, aged 74 years. During his long career Mr. Andrews was intimately associated with the development of submarine telegraphy, his connection with this branch of industry having begun in 1848, under Mr. C. V. Walker, then Electrical Engineer to the South Eastern Railway Telegraphs. In the early fifties he accepted the post of Acting Engineer to the Submarine Telegraph Company, which position he retained for eight years. During this period he was London Secretary to the British and Irish Magnetic Telegraph Company, and gave assistance in extending telegraphic communication with the Continent, and particularly in simplifying tariff charges. In 1860 Mr. Andrews joined the United Kingdom Telegraph Company, as Manager and Secretary, later on taking up the duties of Electrician and Engineer. In 1870, after the transfer of the home telegraphs to the Government, Mr. Andrews joined the Indo-European Telegraph Company, as Manager and Secretary, and later was appointed Managing Director with a seat on the Board. In the early days the Indo-European Company found a difficulty in earning sufficient revenue to cover necessary expenses, and it was Mr. Andrews' work which brought about a reduction of the various payments made to the Government in connection with land lines in this country. These and other negociations proved successful in reducing the standing charges, and the Company became, under his management, a thoroughly sound and regular dividend earning undertaking. In protecting submarine telegraph cables from careless and wanton damage Mr. Andrews took a lively interest, and in association with other distinguished representatives of British submarine cable enterprise he shared in protecting successfully the interests of the Company. After thirty years of active service Mr. Andrews retired at the end of 1899 from the post of Managing Director of the Indo-European Company. In his connection with other telegraph enterprises he was elected, in 1877, a Director of the Western and Brazilian Telegraph Company, of which he became Chairman in 1888. This Company was amalgamated in 1898 with the Brazilian Submarine Company, and Mr. Andrews became Chairman of the combined undertaking, which was registered as the Western Telegraph Company, a position he retained until his resignation in 1902. In 1895 he was elected Chairman of the newly-established Amazon Telegraph Company, and in 1897 he became Chairman of the West India and Panama Company. He was an original member of the Institution of Electrical Engineers.

ALBERT BATTERSBY died in May, 1906, at the age of 36 years. He was educated at the Manchester Central Science Schools, and afterwards served an engineering apprenticeship with Messrs. S. Brooks & Co., West Gordon, and at the Electrical Engineering Company, Ancoats. He was afterwards employed by the Manchester Corporation Electricity Department as assistant at one of the power-stations of the Corporation. In 1897 he took charge of the electric generating plant of the Blackpool Tower, but left there in 1901, when he became inspector for the British Engine, Boiler, and General Insurance Company. He was a member of the Northern Society and became an Associate of the Institution in 1900. He was transferred to the class of Associate Members in 1905.

J. R. CRADDOCK died in March, 1906, at the age of 36 years. He was educated at the Central Technical College of the City and Guilds of London, and served his pupilage with Messrs. Paterson & Cooper. For some time he held a position in the Calcutta branch of Messrs. F. and C. Osler, and afterwards became the chief engineer of the Raub Australian Gold Mining Company. He was elected an Associate in 1894, and was transferred to the class of Associate Members in 1904.

FREDERICK CHARLES DANVERS died on May 17, at his residence, Addlestone, Surrey, in his 74th year. Educated at Merchant Taylors and King's College, he joined the clerical establishment of the East India House at the age of twenty. After the Board of Control had been superseded by the Secretary of State, he was deputed to Liverpool and Manchester, to report on traction engines with a view to their being used in India, where railway construction was in its infancy. He entered the Public Works Department of the India Office, and rose to be senior clerk, and then assistant secretary. He wrote frequently for the technical press on the subjects with which his Department was concerned, and his technical knowledge produced such an impression on the late Lord Iddesleigh, that when he was Secretary of State he sent out to India the detailed designs of Mr. Danvers for solving the problem, still unsettled, of carrying the East India Railway into Calcutta, his proposal being to construct a tunnel under the Hooghli. He was the author of many papers—economic, statistical, and technical—some of which were read before the Society of Arts. He also wrote the Indian portion of "Spon's Information for Colonial Engineers." In 1884 Lord Kimberley selected him for the responsible position of Registrar and Superintendent of Records, a post which he occupied for thirteen years. In anticipation of the fourth century of Vasco da Gama's first voyage to East India Mr. Danvers was deputed to Lisbon in 1891 to examine the Portuguese records relating to that country's brief period of power in the East. His report to the Secretary of State was issued in 1892, and formed the base of his chief work, "The Portuguese in India: A History of the Rise and Decline of their Eastern Empire." He also published other works of historical interest.

Mr. Danvers's connection with the Institution will be chiefly remembered on account of the responsible position he held, from the time of its foundation until the day of his death, of Honorary Auditor, and the Institution owes him a debt of gratitude for the valuable services ungrudgingly rendered for so long a period of its existence.

Mr. Danvers was one of the original Associates of the Institution.

GEORGE A. GRINDLE was one of the passengers who lost their lives in the wreck of the *Hilda*, off St. Malo, on November 19, 1905. Mr. Grindle was intimately associated with the early development of the electrical engineering industry in this country. For some time he was on the staff of the Brush Company, and in 1881 he had charge of the first electric lighting of the City of London. Subsequently he went to India to attend to the interests of the Eastern Electric Light and Power Companies, and it was on his return to England that he began practice as a Consulting Engineer. In 1889 he was appointed Resident Engineer to the Electrical Department of the City and South London Railway, and in 1893 he became Works Manager of the Chloride Electrical Storage Company. Three years later Mr. Grindle was appointed General Manager to that Company, but in 1903 he retired, though he still retained connection with the Firm in the capacity of Consulting Manager. The extension of the Chloride Company's business was largely due to his perseverence, and it was under his active management that the works developed from a few small huts, in 1894, to the present extensive and well appointed shops. Mr. Grindle was elected an Associate of the Institution in 1882, and was transferred to full membership in 1883.

WILLIAM A. KENNETH died, after a long and painful illness, in March at his residence 24, Almondbank Terrace, Edinburgh. He served an engineering apprenticeship with Messrs. Dubs & Co. of Glasgow, attending evening classes at the Technical College there at the same time. Subsequently he joined the Electric Construction Co. at Wolverhampton, with whom he remained during two years. He then returned to Glasgow where he took up a position with Messrs. Mavor & Coulson, Ltd. He left them to join the Edison & Swan United Electric Light Co. at Ponders End, and soon after was offered an appointment with the British Engine, Boiler, & Electrical, Insurance Co., of Manchester, with whom he remained until the time of his death.

He was elected an Associate of the Institution in 1903, and was transferred to the class of Associate Members in 1905.

WILLIAM EDWARD LANGDON died on August 12, 1905, at his residence, Palmeira Gardens, Westcliff-on-Sea. Born in 1832, Mr. Langdon was the son of the late Commander J. W. Langdon, R.N., Assistant-Hydrographer at the Admiralty. After receiving his education at the Royal School, New Cross, he entered the service of the Electric and International Telegraphic Company at the age

of 19, and while so engaged he acted as Assistant to Sir William H. Preece. Shortly afterwards he was appointed to the post of Junior Engineer. On the transfer of the telegraphs to the State in 1870 he took charge of the Telegraph Dept. of the London & South Western Railway Co., but he was subsequently recalled by the Post Office to take up the position of Assistant Divisional Engineer, a post which he held until 1878, when he was appointed Telegraph Superintendent of the Midland Railway Co. The entire block system on the Midland Railway was completely reorganised under his supervision. The total mileage of wire on the Midland Railway increased during his term of service from 8,000 to 30,000, and the number of instruments from 7,000 to 26,000. When Mr. Langdon retired in 1902 there were over 1,000 telegraph stations and 1,070 block signalling posts on the Midland Railway Company's system. There were also eleven generating stations for lighting and power purposes, all of which were established under his direction, the total annual output of these various stations being over 5,000,000 units.

During his connection with the Midland Railway Co., Mr. Langdon erected for the Post Office the trunk telegraph line to Glasgow and the trunk telephone line to the North. At the end of 1902 he retired from the service of the Company, but was retained as Consulting Electrical Engineer. Mr. Langdon read a number of papers before the Institution of Electrical Engineers, and was the author of a well-known work entitled "The Application of Electricity to Railway Working." He was a member of the Institution from the first year of its establishment as the Society of Telegraph Engineers, and in 1877 he acted for a short time as Secretary. He was elected a member of the Council in 1895, and held the office of President for the year 1901–2.

LIONEL J. LANGRIDGE died on March 15, 1906, in his 47th year. He was educated at Clifton College, and began his training in Electrical Engineering under Mr. W. Slingo, at the old People's Palace Laboratory. Many years of private research work followed, and his keen studies with regard to the fire risks of electricity enabled him, as Electrical Inspector to the Royal Insurance Company, whose London office he entered in 1894, to adopt a policy of avoiding unnecessary rules and restrictions. Mr. Langridge was elected an Associate of the Institution in 1895, and was transferred to the class of Associate Members in 1899. He was also a member of the executive of the British Fire Prevention Committee.

PETER JOHN NELSON, Superintendent of Posts and Telegraphs, Perak, Federated Malay States, died on May 18, 1905. He was elected an Associate of the Institution in 1889, and was transferred to full membership in 1899.

CARL HEINRICH VON SIEMENS died at Mentone in March, 1906. Mr. Siemens was born in 1829 at Menzendorf in Mechlinburg.

For the greater part of his life he co-operated with his brothers Werner, William and Friedrich, with the first-named of whom he was instrumental in the development of the firms of Siemens Brothers and Siemens & Halske, and of the several undertakings with which the name of Siemens is associated.

After the death of his father in 1839 he lived for a time in Lubeck, and subsequently completed his time at school in Berlin. Later he became the assistant, in the firm of Siemens & Halske, of his eldest brother the late Dr. Werner von Siemens. After the Schleswig-Holstein war in 1848 Carl entered a chemical factory in Berlin, but he soon quitted this to assist his brother in the maintenance of telegraph lines. In 1851 he represented with Friedrich the Berlin firm at the London Universal Exhibition, and at a later date became Manager of the Paris branch of the firm. In 1852 he came to London to take charge of the London office of his brother William, who was then engaged at Birmingham on research work in connection with the regenerative steam engine. The Russian Government about that time entrusted Siemens & Halske with important telegraph contracts, and Carl Siemens was appointed to take complete charge of the firm's interests in Russia, where owing to his energy and ability the Russian business grew rapidly to very considerable proportions. In 1855 he took charge of a large branch factory at St. Petersburg, and nine years later the London firm, owing to the retirement of Mr. Halske, was reconstituted with the three brothers Werner, William and Carl as partners, the business being carried on from 1865 as Siemens Bros.

In 1869 Mr. William Siemens requested his brother at St. Petersburg to share in the management of the London business, and as the Russian telegraph maintenance contracts had expired he was free to comply with his brother's wishes. For eleven years he worked in conjunction with his brother William, during which period the Woolwich works were gradually enlarged, and the gutta-percha factory established there. Amongst other interests he took an active part in the laying of submarine cables, and in this connection it is interesting to record that he was the first who succeeded in raising from the bed of the Atlantic a broken submarine cable. In 1880 the firm of Siemens Bros. was converted into a limited company, Carl remaining one of the directors, but about this time he returned to St. Petersburg, where he took over once more the management of the Russian business. When Dr. Werner von Siemens died in 1892 Mr. Carl von Siemens was called to Berlin to take up the management of the firm of Siemens & Halske, and in that year also he was elected to the Chairmanship of Siemens Bros. & Co., Ltd., which position he held until his death. As an inventor his name is not so well known as those of his brothers, but he was a man of great energy and perseverance, and was justly celebrated as a capable administrator and organiser. He was an original member of the Institution of Electrical Engineers, and held office as Member of Council from 1873 to 1876, and as Vice-President from 1877 to 1880.

REGINALD FREDERICK YORKE died at Stirling on the evening of March 6, after an illness of three weeks' duration. He was the second son of the late Admiral Reginald Yorke, and was born at Cagebrook, Herefordshire, in 1862. Educated at Marlborough College, he early showed a taste for scientific pursuits. He subsequently went to Cooper's Hill, where, in the study of chemistry, he was the best man of his year. His first practical experience of electrical work was in the service of the Eastern Telegraph Company at Porthcarnow, in Cornwall. Afterwards he was employed at Derby in the Midland Railway's Telegraphic department, under the late Mr. William Langdon, the superintendent. Here he first turned his attention to accumulators, in which he devised various improvements. During the greater part of his professional career he had been occupied with the application of water-power to electric lighting, and many private houses in England and Scotland, as well as the town of Fort-William, bear witness to his success and skill. He took out various patents in connection with electrical development, of which the most important is his tubular system of writing. Mr. Yorke's ability was unquestioned, and he was widely known and respected in his profession.

He became an Associate of the Institution of Electrical Engineers in 1889, and a full Member in 1898.

REFERENCES TO PAPERS READ BEFORE LOCAL SECTIONS OF THE INSTITUTION, AND PUBLISHED, IN FULL OR IN ABSTRACT, IN THE TECHNICAL PRESS, BUT NOT YET ORDERED TO BE PRINTED IN THE JOURNAL OF THE INSTITUTION.

DUBLIN LOCAL SECTION.

"Some Points Relating to Storage Batteries and Boosters," by L. Broekman.

Electrical Engineer, Vol. **36**, p. 842, December 15, 1905.

"Some Notes on Motor Driving," by W. J. Belsey, Associate Member.

Electrical Engineer, Vol. **37**, p. 273, February 23, 1906.
Electrician, Vol. **56**, p. 795, March 2, 1906.

"Gas Producer Plant for Electric Generating Stations," by W. J. U. Sowter, Associate Member.

Electrician, Vol. **56**, p. 1010, April 6, 1906.

"Coal Testing," by John Holliday.

Electrical Engineer, Vol. **37**, p. 490, April 6, 1906.
Electrician, Vol. **56**, p. 1054, April 13, 1906.

GLASGOW LOCAL SECTION.

"The Maintenance of Underground Mains," by G. Black, Associate Member.

Electrical Review, Vol. **58**, p. 114, January 19, 1906.
Electrician, Vol. **56**, p. 507, January 12, 1906.

"Notes on Booster Developments," by A. H. Kelsall, Associate Member.

Electrical Engineer, Vol. **37**, p. 699, May 18, 1906.
Electrician, Vol. **57**, p. 16, April 20, 1906.

"Observations on the Mercury Arc, and some Resultant Problems in Photometry," by C. O. Bastian, Member.

Electrical Engineer, Vol. **37**, p. 736, May 25, 1906.
Electrical Review, Vol. **58**, p. 943, June 8, 1906.
Electrician, Vol. **57**, p. 131, May 11, 1906.

LEEDS LOCAL SECTION.

"Notes on Alternate Current Induction Motors," by T. H. Churton, Associate.

Electrical Engineer, Vol. **36**, p. 590, October 27, 1905.
Electrical Review, Vol. **57**, p. 706, November 3, 1905.
Electrician, Vol. **56**, p. 73, October 27, 1905.

"Destructors and their Bye-Products," by F. L. Watson.

Electrical Review, Vol. **57**, p. 993, December 15, 1905.
Electrician, Vol. **56**, p. 271, December 1, 1905.

"The Cost of Electricity per Unit from Private Electrical Plants," by W. Hartnell, Member.

Electrical Engineer, Vol. **37**, p. 411, March 23, 1906.
Electrician, Vol. **56**, p. 1021, April 6, 1906.

MANCHESTER LOCAL SECTION.

"STREET CABLE SYSTEMS," BY S. J. WATSON, MEMBER.
Electrical Review, Vol. **57,** p. 1029, December 22, 1905.
Electrician, Vol. **56,** p. 314, December 8, 1905.

"THE CALCULATION OF ELECTRIC FEEDERS," BY W. G. RHODES, D.Sc., MEMBER.
Electrical Review, Vol. **57,** p. 1029, December 22, 1905.
Electrician, Vol. **56,** p. 316, December 8, 1905.

"GAS ENGINES AS APPLIED TO ELECTRIC DRIVING," BY J. ATKINSON.
Electrical Engineer, Vol. **37,** p. 235, February 16, 1906.
Electrical Review, Vol. **58,** p. 317, February 23, 1906.
Electrician, Vol. **56,** p. 720, February 16, 1906.

NEWCASTLE LOCAL SECTION.

"THE COMMERCIAL TESTING OF SMALL MOTORS UP TO 15 B.H.P.," BY T. CARTER, ASSOCIATE MEMBER.
Electrical Engineer, Vol. **36,** p. 839, December 15, 1905.
Electrician, Vol. **56,** p. 423, December 29, 1905.

"ELECTRIC WIRING OF SMALL BUILDINGS DURING COURSE OF ERECTION," BY R. ROBSON, ASSOCIATE MEMBER.
Electrical Engineer, Vol. **37,** p. 201, February 9, 1906.
Electrical Review, Vol. **58,** p. 406, March 9, 1906.
Electrician, Vol. **56,** p. 800, March 2, 1906.

"ELECTRIC IGNITION FOR MOTOR CARS," BY F. LITTLE, ASSOCIATE MEMBER.
Electrical Engineer, Vol. **37,** p. 267, February 23, 1906.
Electrician, Vol. **56,** p. 713, February 16, 1906.

"THE REGULATION OF THE PRESSURE OF DISCHARGE OF LIGHTING BATTERIES," BY E. P. HOLLIS, STUDENT, AND E. R. ALEXANDER, STUDENT.
Electrical Engineer, Vol. **37,** p. 706, May 18, 1906.
Electrician, Vol. **57,** p. 216, May 25, 1906.

NOTE.

The Institution is indebted to the Editors of various Technical Papers for the use of some of the blocks employed in this volume of the *Journal*.

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EXPLANATION OF ABBREVIATIONS.

[P] signifies a reference to the general title or subject of a Paper.

[*p*] signifies a reference to a subject incidentally introduced into a Paper.

[D] signifies a reference to remarks made in a Discussion upon a Paper, of which the general title or subject is quoted.

[*d*] signifies a reference to remarks incidentally introduced into a discussion on a Paper.

[*Ref.*] signifies a reference to the place of publication in the Technical Press of a Paper read at a Local Section, and not yet printed in this Journal.

Note.—The lists of speakers in the Discussion upon any Paper will be found in the Table of Contents at the beginning of the volume.

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